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EYE

Vision aids include detectors and rangefinders as well as assistive Braille technologies.

EAR

Cochlear implants of electronics and speech recognition aids to help overcome hearing impairments.

MOUTH

Better algorithms and affordable computing power are making extended speech more common.

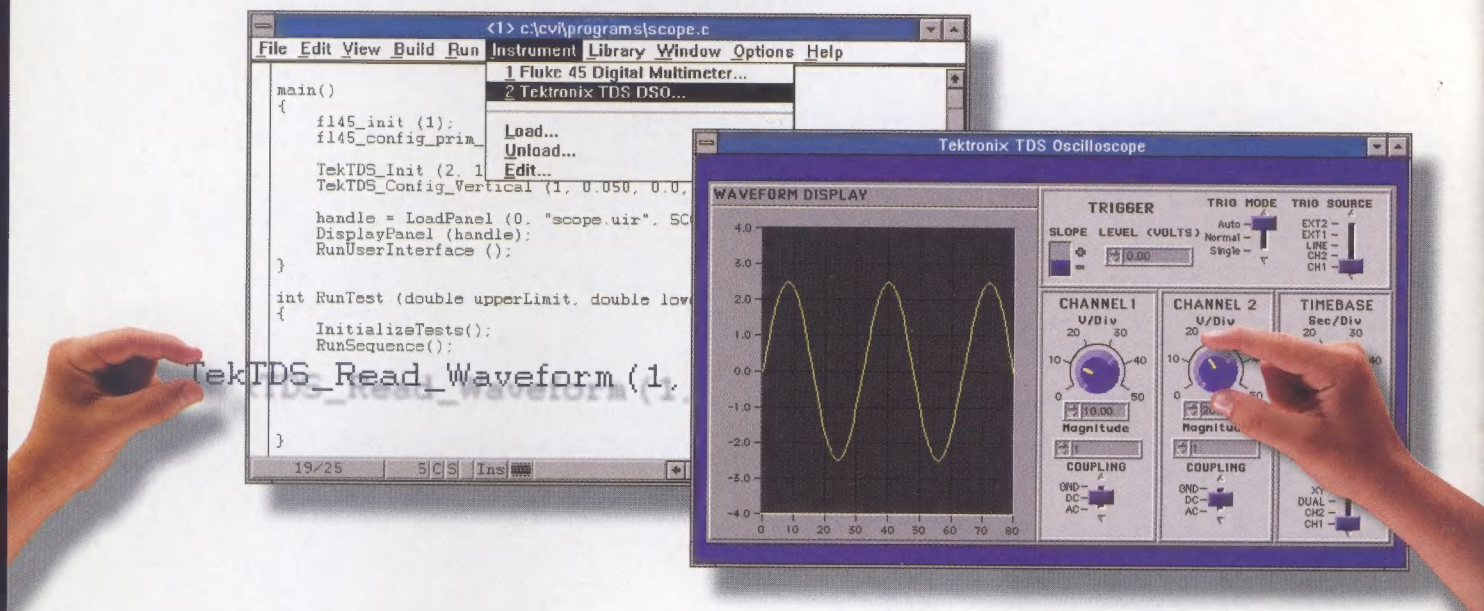
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OCTOBER 1994



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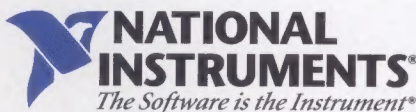
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Newslog

AUG 9. Walt Disney Co., Burbank, Calif., said it would join with **Ameritech, BellSouth,** and **Southwestern Bell** in providing video services to homes. The four said the services being planned include existing broadcast and satellite-TV programming, plus movies, interactive home shopping, and, to give customers easy access to the offerings, an on-screen navigator.

AUG 15. Digital Equipment Corp., Maynard, Mass., said it had built the first commercially available microprocessor that can tackle more than a billion instructions a second, or more than twice as many as the fastest competing chips. The 9.3-million-transistor Alpha 21164 performs at 300 MHz using a four-way superscalar design. It uses over 40 W and measures 16.5 mm by 18.1 mm.

AUG 16. Kansai Electric Power Co., Osaka, Japan's second-largest electric utility, said it had overhauled and restarted its 500-MW pressurized-water nuclear reactor at Mihama. The 22-year-old reactor had been shut down for over three years after its primary cooling system released 55 tons of radioactive water into the secondary system that powers its turbine.

AUG 17. Thinking Machines Corp., Cambridge, Mass., said it would seek Chapter 11 bankruptcy protection after an unsuccessful 10-month effort to negotiate a sale of all or part of the company. The supercomputer pioneer said it had held talks with 20 companies in search of a solution to its financial problems.

AUG 19. Wyse Technology Inc., San Jose, Calif., announced a joint venture with **China's Hospital Administration Institute** to provide advanced computer systems that will help automate operations at as many as 200 000 Chinese hospitals.

AUG 19. ABB Asea Brown Boveri Ltd., Zurich, said it and

Tokyo partner **Marubeni Corp.** had won a US \$733 million order to build a 1090-MW gas-and-oil-fired power station at Maura Tawar, in West Java.

AUG 22. LDDS Communications Inc., Jackson, Miss., said it would buy **Witel,** the telecommunications unit of the **Williams Companies,** Tulsa, Okla., for \$2.5 billion. The acquisition of Witel's national optical-fiber network will give LDDS its own transmission facilities for the first time. LDDS has made more than three dozen acquisitions and mergers in the last four years.

AUG 22. Intel Corp., Santa Clara, Calif., and **AT&T Corp.** said they would work together on a videotelephone based on AT&T's Worldworx videoconferencing network and Intel's Proshare desktop videoconferencing system. Analysts saw the venture as an attempt to jumpstart the desktop videoconferencing market, though companies seem more drawn to group-oriented products.

AUG 30. Lockheed Corp., Calabasas, Calif., and **Martin Marietta Corp.,** Bethesda, Md., said they plan to merge to form a defense-aerospace giant with annual sales of nearly \$23 billion. The new company, to be called Lockheed Martin, will focus on becoming competitive in the specialty areas of its parent companies—advanced military aircraft, electronics, and rockets.

AUG 30. General Signal Corp., Stamford, Conn., and **Reliance Electric Corp.,** Cleveland, Ohio, said they had agreed to merge in a \$1.3 billion stock swap. The deal would permit the new company to compete better in electrical equipment and telecommunications worldwide.

AUG 31. Tokyo District Court ruled that **Fujitsu Ltd.,** Tokyo, was not infringing the patent covering the basic invention of

the IC held by **Texas Instruments Corp.,** Dallas. The court based its decision on the ground that the Kilby patent, as it is called, covers old technology not in use today.

SEP 1. MCI Communications Corp., Washington, D.C., said it had ended a proposed \$1.3 billion deal with **Nexel Communications Inc.,** Rutherford, N.J., the company on which it had based its plans for building a nationwide wireless telephone network. MCI said negotiations were severed because of intractable disagreements with **Motorola Inc.,** Schaumburg, Ill., a major Nexel shareholder that had veto power over a deal.

SEP 1. Japan's National Space Development Agency said it had abandoned attempts to nudge a \$415 million, 2-ton research satellite into its proper orbit. Its Aug. 28 launch marked Japan's first solo development of a geostationary satellite. The loss is a setback for the agency's plans to enter the commercial satellite launching business.

SEP 2. Russian space officials said Lieutenant Colonel Yuri Malenchenko, commander of the orbiting **Mir space station,** manually docked a cargo spacecraft carrying supplies for keeping Mir operating. The commander, with little fuel left, carried out the complicated, remote-controlled maneuver after two automated attempts failed earlier in the week. With no backup spacecraft immediately available and only 10 days' worth of food and water left on Mir, the Russian space program could have been at risk if Malenchenko had failed.

SEP 5. Alps Electric Co., Tokyo, said it had agreed with South Korea's **Gold Star Ltd.** to set up a 50-50 venture to develop next-generation thin-film-transistor liquid-crystal displays. The first Japanese and South Korean LCD joint

venture, it will be located at Alps' central research institute in Sendai, Miyagi Prefecture.

SEP 5. Nikon Corp., Tokyo, said that its Nikon Technologies Division had developed an ultra-precise measuring instrument that is small enough to fit inside the specimen chamber of a scanning electron microscope. The components on the device all fit on a lightweight metal disk that is 10 cm in diameter and 2 cm thick. The device can measure 10-mm² specimens and 0-10- μ m distances with 0.4-nm precision.

SEP 6. MCI Communications Corp. announced a high-speed data service for large corporations that will make use of asynchronous-transfer-mode switches. The digital network, to be in place by December, will allow companies with private communications networks to move voice, data, and video signals at up to 155 Mb/s.

SEP 19. Sun Microsystems Inc., Burlingame, Calif., is scheduled today to announce its next-generation superscalar reduced-instruction-set computing microprocessor. The 64-bit Ultrasparc is the first implementation of the advanced Sparc-V9 architecture. It includes binary compatibility with previous Sparc processors and built-in multimedia support.

Preview:

OCT 24-27. The "Manufacturing Science and Technology Conference" will be held at the Colorado Convention Center in Denver in conjunction with the 41st National Symposium of the **American Vacuum Society.** Cosponsored by the IEEE, the conference will focus on microelectronics manufacturing, including real-time diagnostics and control as well as process integration. For information, call 212-248-0200.

Sally Cahur

IEEE SPECTRUM

SERVICE OF MANKIND

24 Technology combats disabilities

By JOHN A. ADAM

Engineering advances are steadily moving the disabled and elderly toward greater independence. In this issue, *Spectrum* begins a series of articles on the uses of electro-technology in the service of mankind.



27 Advancing step by step

By RUDI KOBETIC

Electric stimulation is helping restore limited mobility and dexterity in arms and legs of persons with stroke or spinal cord injuries, as in the photo below.



Cleveland Veterans Administration Medical Center

DEVELOPING COUNTRIES

32 Appropriate technologies

By GADI KAPLAN

The first articles in a new series on the application of technology to the needs of developing countries focus on photovoltaics, as exemplified in this electric power system for a home in Somalia.



Siemens Solar GmbH

34 Photovoltaics for villages

By ERIK H. LYSEN

A relatively few successful applications of solar photovoltaic electric systems in developing countries may open the door to massive worldwide deployment of similar systems, conditioned upon affordable financing schemes.

40 Water from the African sun

By SERGE MAKUKATIN

One of the world's most ambitious photovoltaic programs is pumping water from wells in the drought-prone Sahel region. An important side benefit is an infrastructure trained in installing and maintaining the systems.

44 Homemade watts for rural India

By TAPAN KUMAR BHATTACHARYA

Subsidized by the government, about 62 000 stand-alone systems supply villages with power for lights, television, and pumping water. Commercial applications to remote VHF radiotelephone links and more are also opening up.

ADVANCED TECHNOLOGY

47 Europe's supercollider project

By WILLIAM SWEET

With the demise of the U.S. superconducting supercollider program, physicists are focused on Europe's Large Hadron Collider project. This collider has a good chance of finding the Higgs boson, which would resolve at least one mystery of matter. It may also yield a "new physics" beyond the current standard model.

GOVERNMENT

55 Defense acquisition: grab the ax

By CHARLES A. FOWLER

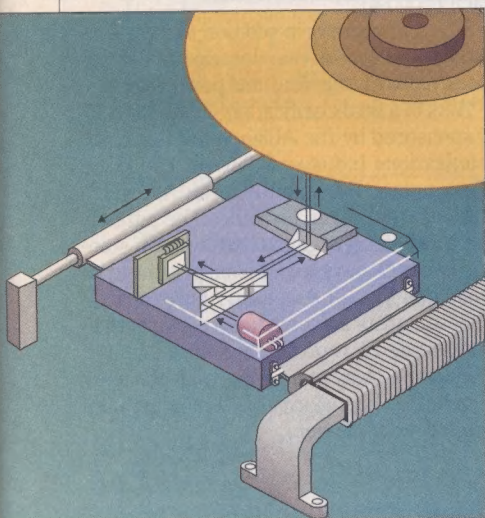
Hefty strokes and the commitment of all concerned are needed if the Department of Defense's acquisition system is ever to be made to work right.

MANAGEMENT

60 The lessons of optical storage

By PRAVEEN ASTHANA

The optical disk drive has been called both a promising technology and a dismal failure. Now that it may finally be taking off, the experience leaves a wealth of marketing tips for future high-tech stars.



PROFESSION

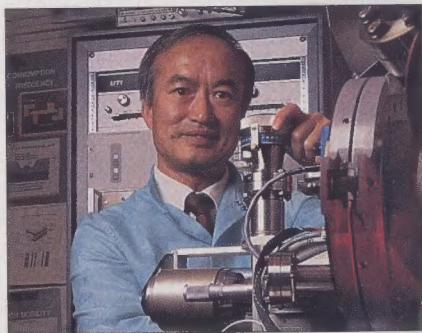
67 Technical fitness

By DAVID B. YOUST and LAURENCE LIPSETT

Maintaining technical skills has a lot in common with staying in good physical shape: you must always be working at it.

COVER: See p. 24. Illustration by Jeff Barcan.

PROFILE



70 Alfred Yi Cho

By TRUDY E. BELL

Love of art, attention to detail, and sheer hard work characterize the developer of molecular beam epitaxy.

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Forum

Engineers for life

Like many of you, I watch with horror the refugee predicament in Rwanda and Zaire. I cannot help but admire the good work performed by the aid agency Doctors without Borders (*Les Médecins sans Frontières*). Is there a comparable organization for engineers, especially for IEEE members? If such a group exists, how do I contribute to it?

If no such group exists, why not? I wonder just how many lives might be saved, and how much misery might be averted, if IEEE members united to provide emergency power for lighting, refrigeration, food preparation, and medical equipment. How much more effectively might services be delivered with better emergency communications? How many more families might be reunited with the aid of simple bulletin board services set up by members? Finally, given the organizational skills of engineers, how many crises might be averted?

I do not consider myself to be a do-gooder, but I do know when something needs to be fixed. Certainly a little sweat spent in Rwanda and other locations would diminish many myths the public holds about engineers. No task so important is easy, so I am most interested in hearing from other members on this subject. My address is 3800 Glen Eagles, #319, Uniontown, OH 44685.

Scott Bugno
Uniontown, Ohio

Reduce, reuse, recycle

In all the high-tech discussion of "Green' refrigerators" [August, pp. 25-30], no mention was made of a technique I consider fairly obvious for energy use reduction in refrigeration.

About \$10 worth of components and some pipe could control a valve that connects to the outside. This valve would be micro-processor controlled and would suck in outside air when it was cold enough to refrigerate or freeze. If this technique were used in the Midwest and Northeast (and much of Europe), energy consumption for refrigerators could be reduced to virtually nothing for three to five months a year.

Naturally, there will be logistics problems in getting the air pipe to the outside, but it is certainly as viable a technique as acoustic refrigeration, and it is available now.

Brian Lowe
Libertyville, Ill.

It was very refreshing to read the articles on electronics recycling. I am vice president

of Hobi International Inc., an electronics recycling corporation. Although at Hobi we apply sound engineering principles in the design of our recycling system, sometimes I feel as if I have fallen off the technology road map.

Little has been written about electronics recycling in any technical publication, but it is a significant problem. Through efforts by corporations and industry professionals, this potential environmental nightmare could be avoided without the limitations of further government regulations. I would hope that the IEEE would continue to develop industrywide interest on this subject to promote corporate involvement and technical collaboration.

Craig Boswell
West Chicago, Ill.

Update on standards

The May article on "The FCC on personal wireless" [pp. 39-46] was both interesting and informative. However, as chairman of the Technical Subcommittee (T1P1) in Committee T1, with the principal responsibility for PCS [personal communications services] standards development, I found the box "Standards in turmoil" somewhat misleading and not current in standards development activity.

The Personal Communications Industry Association is not a standards development organization (SDO) and to my knowledge no serious consideration is being given to turning it into one. It is in fact an association that, among other tasks, develops high-level standards requirements documents as inputs to such standards groups as Committee T1 and the Telecommunications Industry Association.

The box also refers to a group promoting CDMA [code-division multiple-access]. This was an advocacy group aiming to promote its choice in SDOs, not to develop standards.

The impression given that all these groups compete with each other is erroneous. Following a recent industry trend toward "hot" technologies, user groups and industry associations have sprung up along with the SDOs. Ideally these groups and associations should complement the SDOs, providing user requirements and implementation agreements, if necessary. The situation is clearly complex but not in turmoil.

Committee T1 recognized early on the complex multi-forum nature of PCS standards and, in forming the T1P1 subcommittee, gave it a mandate for standards planning and program management as well as for standards development. With partici-

pation from the two industry associations and the IEEE, a comprehensive Program Management Plan has been published (Issue 3, April 1994) and made available to the Federal Communications Commission.

The Joint Technical Committee (JTC) is an innovative cooperative effort between T1 (T1P1) and the Telecommunications Industry Association (TR 46) to develop air interface standards for PCS. Initial objectives support voice at wireline quality, voiceband data (9.6 kb/s), and digital data (64 kb/s using channel aggregation). Of the 16 original proposals, seven remain after consolidation.

In order to meet industry needs, the Program Management Plan called for documenting the seven technologies this year in a series of technical reports for use by potential service providers participating in the planned auctions. Feedback from these providers will then facilitate selection of a subset of the seven technologies for later standardization.

Based on such feedback and agreed-upon performance criteria, standards on selected technologies are planned for the fourth quarter of 1994 through the fourth quarter of 1995. This window takes into account the different level of maturity associated with each proposal.

The T1 program, in addition to the air interface, covers service descriptions, interfaces, network signaling, and performance.

And, in a final clarification: Committee T1 is sponsored by the Alliance for Telecommunications Industry Solutions (ATIS) in Washington, D.C., and not the American National Standards Institute. The latter is the accrediting organization for U.S. standards developers and actually prints the standards that T1 develops. Approximately 1200 scientists and engineers participate in Committee T1, representing more than 100 companies that are voting and observer members. The majority of T1 members are not exchange carriers.

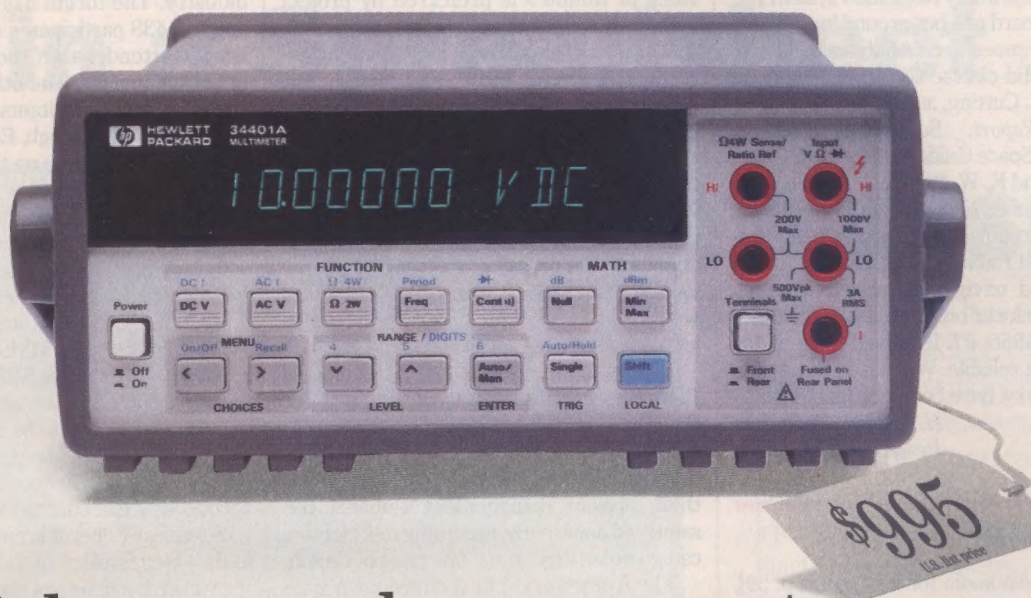
Mel Woinsky
Washington, D.C.

Apollo's history

As supervisor of a guidance and navigation group on Apollo and Apollo applications at North American Aviation, I was particularly interested in the article "L + 25: a quarter century after the Apollo landing" [July, pp. 16-29]. It was quite comprehensive and accurate when compared with other accounts in the general literature.

However, there is a glaring omission in this account, as there is in *Angle of Attack*,

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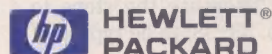
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Circle No. 4

Forum

the biography of the North American Apollo program manager Harrison Storms.

Contrary to the impression left by these accounts, the primary navigation system was not the on-board one but ground based. Two useful references are "Analysis of Radio-command Mid-course Guidance," by A. R. M. Noton, E. Cutting, and F. L. Barnes, *JPL Technical Report*, September 1960, pp. 32-38, and "Space Guidance," by C. R. Gates, J. R. Scull, and K. W. Watkins, *Astronautics*, Vol. 6, November 1961, pp. 24-27 and 64-72.

The Jet Propulsion Laboratory's ground-based S-band radar system, used in Apollo tracking and navigation, was thoroughly tested on the lunar orbiter mission and other missions in 1966-67. It proved to be highly accurate and reliable. Without it, the Apollo goals would not have been obtainable.

H. Stephen E. Schloss
Beverly Hills, Calif.

More about MIDI

In "Multimedia audio for less" [July, p. 59], the author states that sound stored in the MIDI format is technically superior to other formats for generating high-quality sound. But a digital recording of a piece of music delivers a *much* higher-quality sound than a reproduction via MIDI!

And if "generating" is restricted to music produced by synthesis, the author probably means that wavetable synthesis delivers higher-quality sound than FM synthesis—for MIDI is just a format and can be reproduced via any soundcard on the market, including those lacking a synthesizer. A D/A converter is sufficient.

What is meant by "from MIDI to the lower-cost WAV formats"? WAV files are among the most inefficient formats for storing audio, while MIDI is among the most efficient. In fact, MIDI is the lower-cost format, providing multimedia developers with more leeway than the WAV format.

As for price, Soundblaster clones cost \$29-\$49, not \$100-\$150. For that price one can get a wavetable synthesis card—the author's "MIDI card"—which need not cost \$350-\$500. Anyone who wants to spend money might be better advised to consider the Media Vision Pro 3-D soundcard, which sells for \$279-\$299 and (as of July 30) was a state-of-the-art soundcard.

Daniel R. Tauritz
Leiden, the Netherlands

Coping with complexity

I found the response by Wade D. Peterson [August, p. 4] to "Measure the steps to success" [June, pp. 33-38] to be typical of

project managers who would rather do and redo instead of plan.

Few project managers are taught their trade, but rather learn by trial and error. My experience has been that flying-by-the-seat-of-the-pants (what Peterson terms "simple rules of thumb") is preferred by project managers who want to "get things done," so that they can show their management immediate progress.

Spending time in upfront planning and executing that plan in a structured manner takes more time early in the process, and therefore requires faith that the cycle time will be reduced and money saved. It would probably also take a lot of arguing with most company vice presidents—who have come up through the ranks like Peterson—and would put the project manager's job in jeopardy.

I think it interesting that the projects Peterson mentions (the atomic bomb, the Panama Canal, and the creation of streptomycin) are all 50 to 80 years old. It is a shame that while technology has come so far since then, project management remains the same and apparently, according to Peterson, can go no further than a few rules of thumb.

The framework put forward by Wayne A. Mackey and John C. Carter is an excellent vehicle for new project managers to use. Just as Peterson said, they will have to rely on leadership, but communication and accountability are inherent in the Mackey-Carter design, while tenacity is a trait that a project manager had better possess, and simplicity applies more to Peterson's thinking than to any of the complex projects he mentioned or that current project managers have responsibility for.

Michael A. Ferraro
Alexandria, Va.

Smart networks

I have some comments to make on Reza S. Raji's response to my letter [August, p. 4]. Regarding the MMS acronym: it should be the Manufacturing Message Specification not the Manufacturing Messaging Service.

I do not dispute the facts of Raji's article. What I do dispute is the scope and objectivity. Just as any article can be construed as biased, any claim can be proven by selectively including or excluding data.

I have not focused on the author's level of involvement in the industry as claimed. My focus was on the author's objectivity based on his financial involvement with one of the products being compared. (It's like asking a father who is the best player on his son's baseball team.)

The author claims that "a thorough and complete analysis can only be properly done by someone who is involved in the field." MMS, however, has been a heavily used control protocol within the manufacturing

industry for years, both in the United States and overseas.

The Electric Utility Industry established the MMS Forum approximately two years ago to address its application in all aspects of command and control within the utility industry. The forum has met seven times and has 438 participants on record as registered attendees. Of those, 170 are from utility companies. The others are vendors, suppliers, and consultants to the industry.

Interestingly enough, Echelon [Raji's employer] has one name on the list and has attended one forum. This would imply that Echelon is aware of the effort to adopt MMS as a ubiquitous control protocol but is not involved. By Raji's own words, it would seem that his article could not have been a "thorough and complete analysis" [that was] "properly done"!

As for the use of MMS over LonWorks, people are trying to put MMS over a lot of different stacks. The fact remains, however, that MMS was designed to be used on top of the OSI [open systems interconnection] protocol stack and is closely coordinated with standards bodies that control the lower layers.

So, unless Echelon is an active participant in the Open Implementors Workshop run by the National Institute of Standards and Technology, and unless LonWorks conforms to the Stable Agreements produced by the vendors at the workshop who truly are trying to build robust and interoperable solutions, the result of a LonWorks "port" will still be closed, non-interoperable, and proprietary.

Finally, just as with any proprietary system, the users have to pay. The fee may not be a "royalty" as such. Two of my associates who are familiar with LonWorks (one inside the company that manufactures the chip) confirm that the protocol cannot be used without either purchase of the chip set (which is proprietary to Echelon), or payment of a fee of some sort to Echelon.

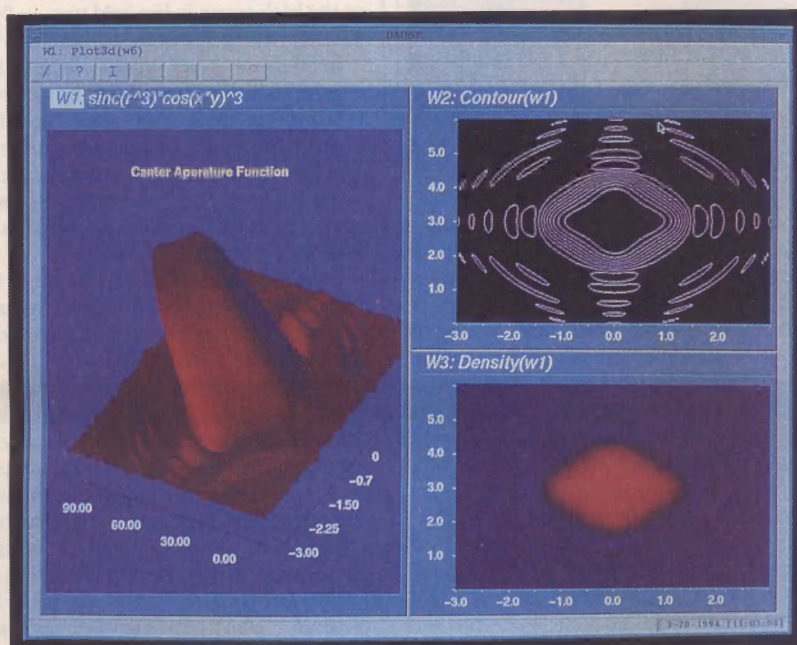
Joe Waggoner
Richardson, Texas

Corrections

On p. 20 of the August issue, Fig. 1 should have been attributed to J. Ertel, "Current Technologies for the Valorisation of PCBs and Electronic Waste," *Proceedings of the International Symposium on Electronics and the Environment* (IEEE, Piscataway, N.J., 1994). Figure 2 should have been attributed to Patricia S. Dillon.—Ed.

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*, on the policies and operations of the IEEE, and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017, U.S.A.; fax, 212-705-7453. The e-mail (Internet) address is n.hantman@ieee.org.

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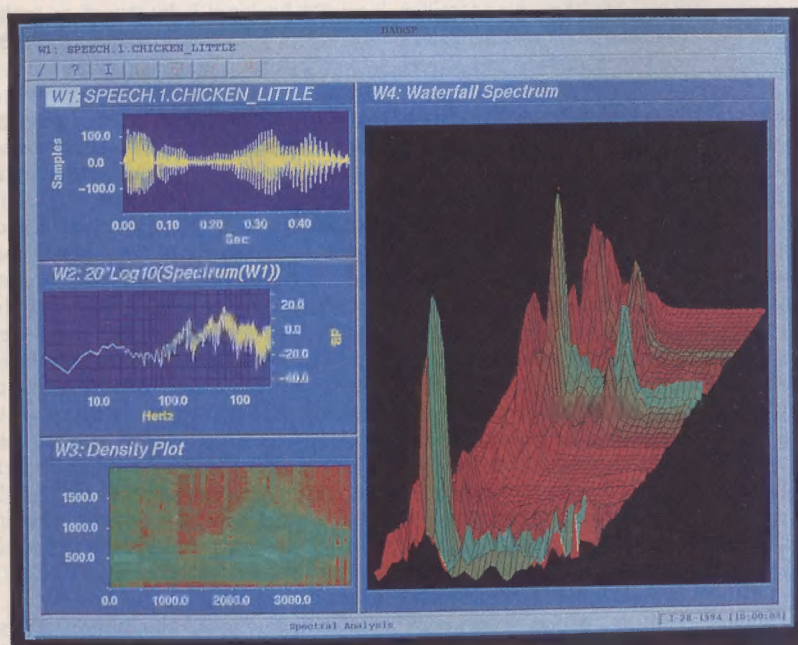
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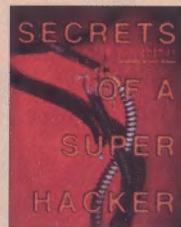
Books

Hacker's how-to

Mihai Nadin

Secrets of a Super Hacker.

The Knightmare,
Loompanics Unlimited,
Port Townsend, Wash.,
1994, 205 pp., \$19.95.



"Code Crackers Not Crooks, Professor Says." The headline perched atop an Associated Press story, and went on to say: "If a professor could have his way, hackers who crack top-secret computer codes would not be regarded as crooks but as eloquent manipulators of their favorite language."

For the record, I was the professor, and the sentiments expressed actually were more or less mine. In view of this history, my reading of this self-described "encyclopedic account of the methods by which security is breached and systems penetrated" might be perceived as biased. Readers, beware.

It has not been so long since hackers were celebrated. John Badham's motion picture *War Games* (1983) opened the gates to many of the now-familiar stereotypes regarding hackers. Youngsters even began aspiring to hacking and phonephreaking rather than fire-fighting or space exploration. Then followed, unsurprisingly, the demonization of the hacker.

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The author declares a hacker to be someone "with an intense love of something, be it computers, writing, nature, or sports. A hacker is a person who, because he or she has this love, also has a deep curiosity about the subject in question.... For a computer hacker that means he respects the ability of computers to put him in contact with a universe of information and other people,

and it means he respects those other people and does not intentionally use this knowledge of computers to be mischievous or destructive."

This seems so disingenuous that I cringe. It comes from the same person proclaimed on the back cover, in big, bold type, as "every security manager's worst nightmare!"

Inside, we read about "brute force attacks," which refer to "hurling passwords at a system until it cracks"; "spoofing," which is "designing dummy screens and delivering fake e-mail"; decryption of password files; and "stair-stepping," which means using a "low-level account to gain ever-higher levels of access."

We also read how to sort through trash (after scavenging, "take a shower when you get home," the author advises), and how to examine found disks and screen shots. Snooping and "shoulder surfing," in which "a hacker looms over the shoulder of a legitimate user that logs on to a computer system," are also described. In between, the author sketchily outlines elementary notions of access control, communication software, modems and speed, bar codes, computer viruses, and so on.

The main message, with which the book closes, is: "Don't get caught!" The message is amplified with a list of things to avoid—the "five ways you, the hacker, can get caught hacking: 1. by traces or technical means, 2. by being finked on, 3. by getting many agencies ganged up against you, 4. by making a mistake, or 5. by being [recognized]." If hacking merely expresses love for computers, and if hackers are so respectful, why worry about being caught?

This is a book that delivers a mixture of methods and ideas for breaking into other people's systems, and then follows that up with a code of ethics. Though this code emphasizes individual responsibility, some of its elements are controversial. To his (or her) credit, The Knightmare does address some of the big, difficult questions: access to information; the appropriate use of technology to empower people and not restrict their creativity or liberties; individual rights regarding data pertinent to people's lives; and a system of checks and balances in the digital domain, especially in the use of and commerce in databases affecting an individual's right to privacy.

"It is pointless," the author writes, "to raise the issue of 'Do you honestly think you can justify snooping with your loopy code of ethics?'" A good point, and this brings up the central issue of such a book. Hacking, as the author notes, can be considered an ex-

(Continued on p. 9)

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Nomadic computation, voice and handwriting recognition, living and working on the information grid, and virtual reality are the new territory of what hacking used to be. Unfortunately, they are not to be found in this book. On the contrary, readers might wonder why *The Nightmare* pays so much attention to MS-DOS (Unix is mentioned, too), when so much of today's computation takes place on other platforms.

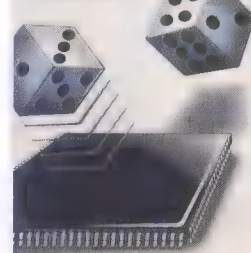
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(Continued on p. 9)

Books

(Continued from p. 8)

pression of passion. But is it also exempt from moral and social constraints?

As Ken Thompson received the Turing award for his co-invention of Unix—the most hacked operating system—he made a point of explaining his attitude toward hackers: “The acts performed by these kids are vandalism at best and probably trespass and theft at worst. It is only the inadequacy of the criminal code that saves the hackers from very serious prosecution.”

I wish the words were not his. Although Thompson’s statement does indeed apply to many hacking cases—including most of the activities described by *The Nightmare*—he misses the critical point. In fact, Turing himself would have been jailed if the criminalizing of code breaking had been applied to him. This requires elaboration, because the book I am reviewing misses this same point, too, but from the opposite direction.

In *Hackers* (Anchor Press/Doubleday, 1984), still the best book on the subject, Steven Levy noted that in the early 1960s, “a project undertaken or a product built not solely to fulfill some constructive goal, but with some wild pleasure taken in mere involvement, was called a ‘hack.’” Levy added that “the artistry with which one hacked was recognized to be considerable.” Programming was coming of age, and Peter Samson’s code that converted Arabic into Roman numerals was one of the more celebrated hacks. At the annual MIT open house in May 1962, hackers fed into a PDP-1 minicomputer paper tape with 27 pages worth of assembly language code comprising a science fiction game written by students. Thus the interactive game was born—as a hack.

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nology. But after stating this in the book’s opening, he or she abandons any pursuit of broader issues. Sensationalist expositions of methods (some disputable, some ingenious, none new) obscure the more fundamental question of why people hack.

The desire to understand is a basic one, and is the downfall of all sorts of barriers to knowledge. Social, cultural, economic, and genetic codes have all been broken, leading me to believe that writing laws that criminalize hacking, without taking into account the specific nature of computer knowledge and access to it, is as ill-advised as writing a book on the so-called “secrets of a super hacker.” Societies scared of hackers to the point of criminalizing them lose more than they think they gain by doing so. Gareth Branwyn, who knows quite a bit about the subject, provides good arguments along this line in the book’s introduction.

The author frequently comments on obsolete statutes regarding computer crime. However, the break-in methods described are similarly anachronistic, carrying over fundamental misconceptions from previous pragmatic frameworks. As science becomes more and more computational, we need to come up with a better understanding of the nature of human activity in the Information Age. The New Frontier Foundation, mentioned in this book, is probably best equipped to help in this respect.

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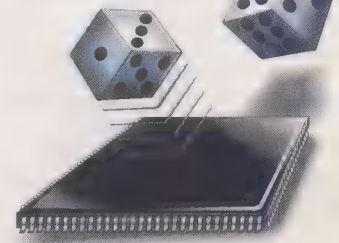
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Books

was not already aware. Instead of holding this against the writer or publisher, I would like to turn it into a final observation.

To hack means to be on the frontier, on the border. In computer science and technology, this border is constantly being pushed back, and at a tremendous pace. In truth, a good "how to" book cannot be written on hacking, because with each new hack, a higher level of knowledge is reached that requires newer methods to surpass. To explain hacking, therefore, is to explain it away.

Mihai Nadin (SM) heads the computational design department at the University of Wuppertal in Germany. Previously, he was eminent scholar in art and design technology at Ohio State University in Columbus. One of the early researchers in computer graphics in Europe, he is the author of *Mind Anticipation and Chaos* (Belser Publishers, 1991) and a just-completed work, *Civilization of Illiteracy*, as well as many articles.

A painstaking fuzzy primer

Joe Altnether

The Fuzzy Systems Handbook: A Practitioners' Guide to Building, Using, and Maintaining Fuzzy Systems.

Earl Cox. Academic Press, San Diego, Calif., 1994, 615 pp., \$49.95.



Logic can be broadly divided into two distinct types: the strict, formal Aristotelian logic that is used to prove an assumption, and the less rigid logic we all use every day.

Aristotelian logic is dichotomous—an element either belongs to a set or it does not. Simultaneous membership in a "true" set and a complement set is forbidden by the law of non-contradiction. An animal cannot be a cow (in other words, a member of the set of cows) as well as a dog (a non-cow) at the same time.

Computer technology today is based on this logic. Ones and zeros comprise two different sets. Precise data input, from files or sensors, say, complements this methodology.

Human beings, however, have imprecise sensors. True, the ear and eye can both distinguish and perceive subtle differences, but neither can provide an exact value of the frequency heard or color seen. Because of this fuzziness, there is an inherent uncertainty in an element's membership in a set. If I ask someone to turn the air conditioner down a little, he or she will probably comply with my request, vague though it is. How many degrees is "down a little"? For that matter,

what does "down a little" actually mean? Does it mean to reduce the temperature and make it colder, or does it mean to reduce the output and make it warmer?

The relationship between humans and machines has been frustrated by the disparity between human and machine logic. Fuzzy logic was developed as a means of coping with the inherent imprecision and vagueness of many classes of problems. Now, after languishing in the wings for several years, it has been thrust onto center stage, the subject of intense curiosity and scores of books. The books can be divided into three categories: all theory; quickies that give a first level of understanding; and practical applications by the few who have had hands-on experience with the topic. Fortunately, Earl Cox's book is in this third category.

Fuzzy logic can be a solution methodology for both event-control and information management applications. Many of the examples and books on fuzzy logic have so far focused on the event-control applications. Cox, on the other hand, draws on his experience in information management and uses these applications as examples. This topic has received scant attention until now.

The book concentrates on information handling and decision-making and, fortunately, is general enough for the material to be applicable to control systems as well. Control applications are directly addressed in a mere two pages, in which the Mandami fuzzy control of a steam turbine is compared with a proportional-integral-derivative routine. Cox's perspective on control applications would have been welcome.

It seems these days that all technical books must include a disk of software, and this one is no exception. The difference, though, is that the software included with this book is not of the demo variety. The book balances well-written explanations of fuzzy concepts with the listing of included software (along with explanations). Each of the concepts, and even the software to use the concepts, is explained. Finally, examples of output are illustrated.

The primer's 10 sections, which I hesitate to call chapters, range in length from 20 to 107 pages. While it is proclaimed a "practitioner's guide," the book actually begins with simple ideas, assuming no substantive knowledge of fuzzy logic. The first half-dozen sections cover the basic concepts needed to model a fuzzy system, while the last four focus on fuzzy models, case studies, the building of fuzzy systems, and the use of fuzzy code libraries. Each of the sections begins with a brief outline of the topics to be discussed, and builds in logical fashion on its predecessors.

In the first one, for example, Cox discusses "the rationale behind fuzzy modeling," and then goes on to introduce "the ideas of fuzzy set and a linguistic variable,

differentiate between fuzzy logic and the more general area of approximate reasoning, trace the history of fuzzy set theory and outline the benefits of using fuzzy logic in information system modeling."

The second section moves into a general discussion of imprecise information and sets forth the concept that fuzziness is an integral part of continuous spectrum data. In the third section, the concepts of fuzzy logic and fuzzy sets are developed. Classical, or Boolean, logic and fuzzy logic are clearly delineated. Only one topic remains before the elements of modeling can be introduced, and that is hedges. Analogous to adverbs, hedges permit the designer to model the semantics of the problem.

Beginning in section six, the concepts of earlier sections are integrated to develop a methodology for modeling fuzzy reasoning systems. For the sake of completeness, the concepts of approximate reasoning and fuzzy theory are linked.

The next section puts the theory into practice. Fuzzy modeling software is discussed, and fuzzy model structure and modeling techniques are combined to use the concepts of the preceding chapters.

Section eight is the heart of the book. Of its several case studies, the previously mentioned steam turbine is given first, but the decision problems are the most interesting. For instance, one develops a pricing model for a new product. These decision problems were difficult to solve using classical methods, and drew on the experience and knowledge of the implementer. In his primer, Cox uses fuzzy logic to model the decision problem and discusses how to evaluate the defuzzification strategies. The final case study in the section concerns risk assessment, and reminded me of work done in earthquake risk assessment by Timothy Ross at the University of New Mexico.

I found several minor irritants. References to the best Cajun cooking in New York City will date the book. Problems occur in some graphs; in one case an *x*-axis is skewed (Fig. 3.11) so that the graph and an explanation referring to it do not agree. The index is off by two pages on entries in the glossary, and, finally, the computer-generated graphs are archaic.

Nonetheless, this is a well-written, well-conceived book that will serve as a working manual for years to come. In this one volume, the author has opened up a whole new class of applications for fuzzy logic.

Joe Altnether is fuzzy logic program director at Intel Corp., Chandler, Ariz. He has worked at Intel on applications of microcontrollers in embedded control for over 16 years. Previously, he was a design engineer involved with applications ranging from antisubmarine warfare to computer-aided tomography (CAT) scanners.

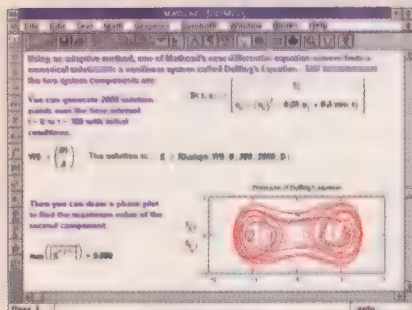
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A pyrotechnical test for smokestack pollution

When metal salts are ignited, they emit light of a characteristic color: strontium emits red, sodium yellow, barium green, and so on. That fact has been known for two centuries to the makers of fireworks. Now it has been applied by a team at Sandia National Laboratories in Livermore, Calif., to measure the concentration of toxic metals spewed out by factories, incinerators, and power plants.

In laser spark spectroscopy, as the technique is called, the metal atoms are heated not by exploding gunpowder, but by a focused, high-energy laser beam. The result is a single spark—not a shower—as the metal particles and molecules dissociate into energized atoms, which radiate light as they return to lower energy levels.

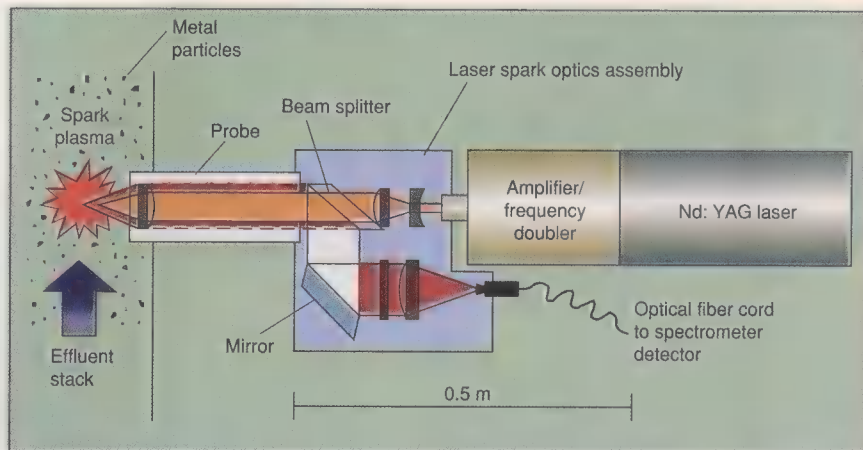
The light radiated from each metal has a spectrum as unique as a fingerprint. And, "because its intensity increases with concentration, we can also infer how much of each species is present," said team leader William Flower.

The approach should help operators measure metal levels both *in situ* (in the emission stacks) and in real time (as the metals are being released into the environment). Current techniques, based on manual collection of samples followed by chemical analysis, are neither *in situ* nor real time. A sample may misrepresent what is actually in the emission stack, and even if representative it takes time to analyze—typically two to four weeks in the laboratory.

The inability to monitor emissions directly has unhelpful consequences. An industrial plant that requires an operating permit usually undergoes a trial run to establish the worst conditions under which it can meet air-quality requirements. This procedure constrains later operations, yet fails to guarantee that emissions will stay within limits.

With a continuous monitor, though, a facility's operators could continuously measure its toxic metal emissions under various conditions. "Laser spark spectroscopy's continuous, accurate feedback would allow you to save money by better utilizing the equipment you have and still be in compliance," noted Flower. "It would also make it possible to assure neighbors and regulators on a day-by-day basis that you are remaining in compliance when processing parameters change."

Under the sponsorship of the U.S.



Department of Energy's Office of Environmental Restoration and Waste Management, Sandia is developing just such a continuous-monitoring instrument for use in hazardous-waste incinerators and other thermal treatment units. Lab tests were done on the 11 toxic metals regulated under the Clean Air Act, with impressive results. Flower, along with his co-workers Lawrence Peng and Kenneth Hencken, measured all of them in concentrations below 250 parts per billion (ppb) and the more important, such as beryllium and chromium, at concentrations as low as 1 ppb. These figures mean the Sandia device could verify compliance with air-quality standards.

The Sandia team has recently designed and built a first prototype of a unit that monitors metal emissions from an operational hazardous-waste incinerator. Field tests this year of the transportable monitor were encouraging, said Peng. Such a device might also be used in munitions deactivation furnaces, fossil-fuel power plants, industrial furnaces and boilers, and industrial processes such as chromium electroplating.

Light-emitting plastics look better

Two engineers at the University of Rochester in New York State have discovered why optoelectronic polymers emit light. Better still, they have used that knowledge to quadruple the materials' highest reported efficiency of light emission to 42 percent, which could make them widely useful.

Optoelectronic plastics, also known as conjugated polymers, are an inexpensive and convenient alternative to light-emitting semiconductors for some uses, such as displays. But it is hard to control the amount

and color of the light they emit, and they are notorious for taking in 10 times the photon energy as they give out in light.

The cause is revealed in the Aug. 5 issue of *Science* by Samson Jenekhe, associate professor of chemical engineering, and his former graduate student John Osaheni, now a research engineer with General Electric Corporate Research and Development in Schenectady, N.Y. They fault the spacing of the molecular chains within the polymer. Apply a voltage to a polymer containing chains only 0.3–0.5 nm apart, and those chains form pairs of molecules known as excimers that exist for only a few nanoseconds. Excimers do not emit light efficiently.

To remedy matters, Jenekhe and Osaheni simply prevent excimers from forming. That can be done by blending in another polymer or other molecules to keep the original polymer's chains at least 1 nm apart. Properly blended, the chains form not excimers but another type of material—a short-lived molecular sandwich known as an exciplex, which emits light very efficiently. The two Rochester engineers believe that conjugated polymer exciplexes signify a new class of optoelectronic materials.

Most exciplexes they have made so far are three to five times as efficient as their pure counterparts at converting input energy into light. But in turning light into electricity (for, say, solar energy), they do strikingly better, being as much as 300 to 1000 times as efficient.

Jenekhe and Osaheni worked on materials called polybenzobisazoles (PBZAs). They have filed for a patent on the new class of materials and their optoelectronic applications, through Research Corporation Technologies of Phoenix, Ariz.

EDITOR: Trudy E. Bell



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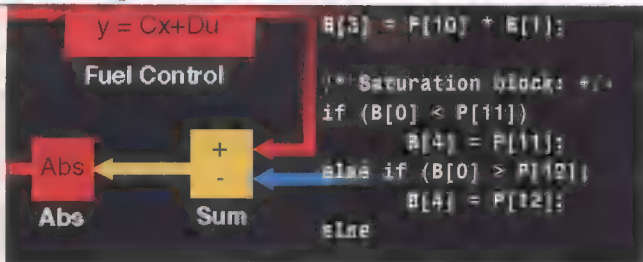
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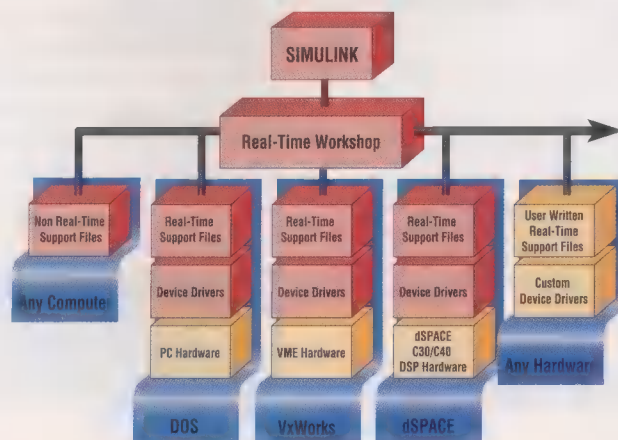
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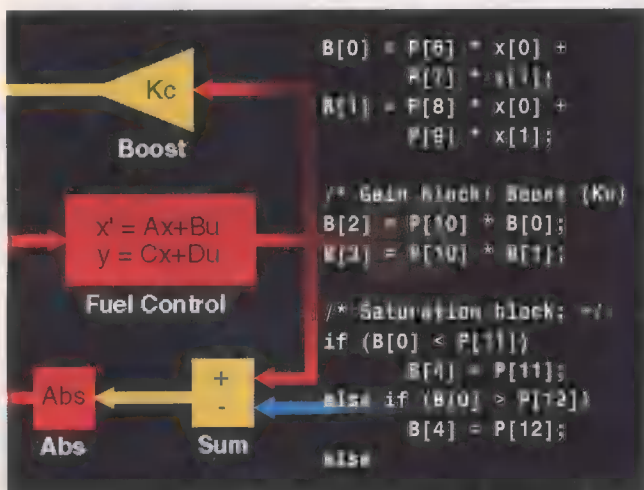
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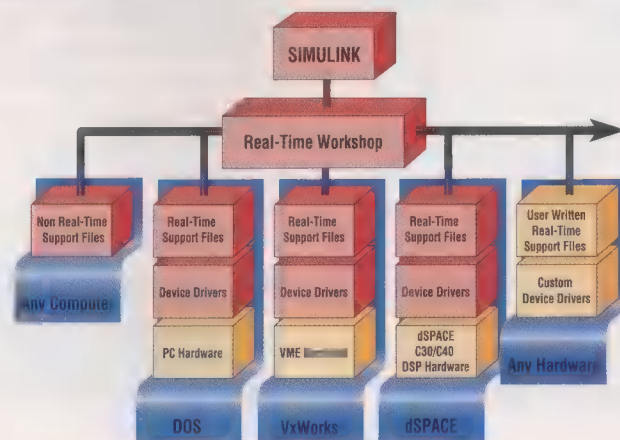
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Gallium Arsenide Integrated Circuits Symposium (ED, MTT); Oct. 16-19; Wyndham Franklin Plaza Hotel, Philadelphia; Donald D'Avanzo, Hewlett-Packard Co., 1412 Fountaingrove Parkway, Santa Rosa, CA 95403-1788; 707-577-2644; fax, 707-577-2036.

International Integrated Reliability Workshop (ED); Oct. 16-19; Stanford Sierra Camp, South Lake Tahoe, Calif.; Tin Yau Ying, Mitre Corp., 202 Burlington Rd., MS: H113, Bedford, MA 01730; 617-271-8170; fax, 617-271-2734.

Holm Conference on Electrical Contacts (CPMT); Oct. 17-19; Holiday Inn, Chicago

City Centre; Holm Conference Registrar, IEEE Technical Activities, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3895; fax, 908-562-1571.

International Conference on Materials for Microelectronics (ED); Oct. 17-19; Hotel Ferin Palace, Barcelona, Spain; Juliet A. Upton, Institute of Materials, Conference Department, 1 Carlton House Terrace, London SW1Y 5DB, England; (44+71) 235 1391; fax, (44+71) 823 1638.

International Engineering Management Conference—EM '94 (EM, Dayton Section); Oct. 17-19; Marriott Hotel, Dayton, Ohio; Roy Gregg, 448 Merrick Dr., Beavercreek, OH 45434; 513-258-1170; fax, 513-253-9765.

International Conference on Neural Information Processing (NN); Oct. 17-20; Swiss Grand Hotel, Seoul, Korea; Iconip '94 Seoul Secretariat, c/o Intercom Convention Service Inc., SL, Kang Nam, Box 641, Seoul 135-606, Korea; (82+2) 515 1560; fax, (82+2) 516 4807; e-mail, ICONIP@cair.kaist.ac.kr.

International Conference on Power System Technology (PE, Beijing); Oct. 18-21; P.Y. Wang, Electric Power Research Institute, Qinghe, Beijing 100085, China; (86+1) 291 3201; fax, (86+1) 291 3126.

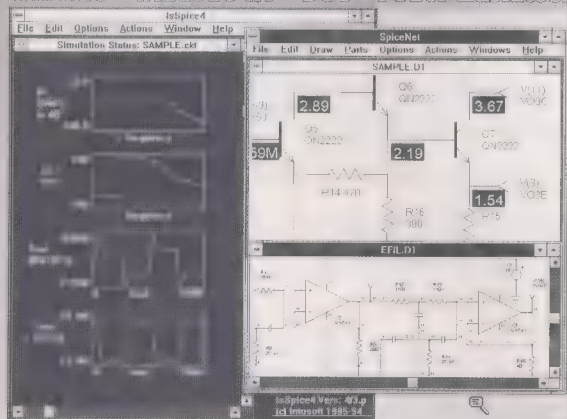
Workshop on Power Electronics in Transportation (IE, PEL); Oct. 20-21; Hyatt Regency Hotel, Dearborn, Mich.; V. Anand Sankaran, MD 2036/SRL, Ford Motor Co., Box 2053, 20 000 Rotunda Dr., Dearborn, MI 48121-2053; 313-390-8689; fax, 313-323-8239.

Conference on Electrical Insulation and Dielectric Phenomena—CEIDP '94 (DEI); Oct. 23-26; Arlington Marriott, Arlington, Texas; Alan Watson, Department of Electrical Engineering, University of Windsor, Box 33830, Detroit, MI 42832; 519-253-4232, ext. 2581; fax, 615-973-7062.

13th Symposium on Reliable Distributed Systems (C); Oct. 25-27; Dana Point Resort, California; Kane Kim, Department of Electrical and Computer Engineering, University of

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International Symposium on Time-Frequency and Time-Scale Analysis (SP); Oct. 25-28; Adam's Mark Hotel, Philadelphia; Ralph Nadel, Palisades Institute for Research Services Inc., 201 Varick St., New York, NY 10014; 212-620-3341; fax, 212-620-3379.

Fifth International Conference on Power Electronics and Variable-Speed Drives (IA); Oct. 26-28; IEE Savoy Place, London; Jane Chopping, IEE Conference Services, Savoy Place, London, WC2R OBL, England; (44+071) 240 1871; fax, (44+071) 497 3633.

International Symposium on Guided-Wave Optoelectronics: Device Characterization Analysis and Design (LEO); Oct. 26-28; Polytechnic University, Brooklyn, N.Y.; Samantha H. Phillips, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3894; fax, 908-562-1571; e-mail, s.phillips@ieee.org.

26th Symposium on Stochastic Systems Theory and its Applications (Tokyo Chapter—CS, GRS, SMC); Oct. 26-28; Mita

Press/Osaka, Umeda Center Building, Osaka, Japan; Y. Sunahara, Mita Press, Kyoto Annex, Asahi Karasuma Building 4F 381, Shimizu-cho, Karasuma-East, Takeya, Nakagyo-ku, Kyoto 604, Japan; (81+75) 211 1055; fax, (81+75) 211 1135.

Workshop on VLSI Signal Processing (SP); Oct. 26-28; Embassy Suites Hotel, La Jolla, Calif.; C. Schaffer, Electronic Research Laboratory, EE Department, Berkeley, CA 94720; 510-643-6680; fax, 510-642-2739; e-mail, schaffer@eecs.berkeley.edu.

Sixth Symposium on Parallel and Distributed Processing (C, Dallas/CC); Oct. 26-29; Bristole Suites Hotel, Dallas; David Padua, University of Illinois 465CSRL, 1308 W. Main St., Urbana, IL 61801-2307; 217-333-4723; fax, 217-244-1351; e-mail, padua@csri.uiuc.edu.

Workshop on Information Theory and Statistics (IT); Oct. 27-29; Holiday Inn, Alexandria, Va.; Prakash Narayan, EE Department, University of Maryland, College Park, MD 20742; 301-405-3661; fax, 301-314-9281.

International Telecommunications Energy Conference (PEL); Oct. 30-Nov. 2; Hotel Vancouver, B.C., Canada; Ed Parker, Northern Telecom Canada Ltd., 150 Montreal

Toronto Blvd., Lachine, PQ H8S 1B6, Canada; 514-639-3030; fax, 514-639-3002.

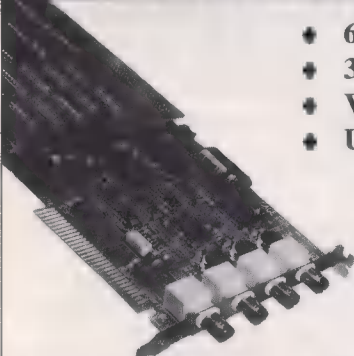
Nuclear Science Symposium—NSS '94 (NPS); Oct. 30-Nov. 5; Waterside Marriott Hotel, Norfolk, Va.; Lowell A. Klaisner, Stanford Linear Accelerator Center, Box 4349, Mail Stop: 30, Stanford, CA 94309; 415-926-4463; fax, 415-926-3654.

28th Asilomar Conference on Signals, Systems, and Computers (SP, C); Oct. 31-Nov. 2; Asilomar Hotel and Conference Grounds, Pacific Grove, Calif.; James A. Ritcey, EE Department, FT-10, University of Washington, Seattle, WA 98195; 206-543-4702; fax, 206-543-3842.

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Gigantic problem

Kevin Self

What is the correct way to pronounce the first *g* in *giga*, we were asked by reader R.E. Lafferty of Morris Plains, N.J. He recalled seeing a document about 30 years ago from the National Bureau of Standards (now the National Institute of Standards and Technology), in which the pronunciation of the prefix meaning *billion* was given as soft, or a *g*, as in *giant*.

Technically Speaking's perusal of the brochure on metric practice put out by the IEEE and the American National Standards Institute (ANSI) supported Lafferty's earlier research. The brochure's guide to U.S. pronunciation of metric prefixes states that it should be pronounced *jig' a* (*j* as in *jig*, *a* as in *about*)—in other words, with a soft *g*.

This column has often noted that might makes right when it comes to linguistic misuse. And Lafferty, too, wondered if "with perhaps 90 percent of the technical population using the hard *g*, it would seem prudent to abandon what is, or was, correct, and flow with the tide."

According to the 1970 *Oxford English Dictionary*, the prefix *giga* derives from *gigas*, Greek for *gigantic*. The first (and third) letter of the Greek word is *gamma*, familiar to most engineers as a hard *g*.

This apparent contradiction sent us for clarification to Everdeen Tree, a lecturer in Latin (and a Greek scholar) at the University of Houston in Texas. She informed us that although *gamma* was sounded as a hard *g* in classical Greek, the pronunciation of words that are transliterated into English generally conforms to English usage. In this case, *g* followed by *i* becomes soft, while *g* followed by *a* becomes hard.

Tree noted that pronunciations do change over time, however, based on current usage and new historical data. "Originally, gamma was pronounced with a hard sound," she said. "The soft gamma appeared in the Greek language after the classical era, and in some circles there is a preference for pronunciation closer to the original. Maybe it is time for a change."

Metric muddle

The proper use of metric standards is a popular topic. The ANSI/IEEE Metric Practice brochure mentioned above decrees: "When a quantity is expressed as a numerical value and a unit symbol, a space should be left between them." Yet Allan

Mossberg of Green Valley, Ariz., wrote in to alert us that "a bureaucrat is making a mess of metric spelling."

He supplied two nutritional information panels, presumably from before and after the recent changes in U.S. nutrition labeling requirements went into effect. The new label shows measurements of fat and cholesterol with no space between value and unit, such as 65g, whereas the older label shows a space before the unit.

An investigation of the official Technically Speaking pantry uncovered a perplexing potpourri of metric usage: some of the old-style labels did conform to the ANSI/IEEE standard, but no product with the new style separated unit and symbol. We wondered if perhaps the Food and Drug Administration (FDA), Washington, D.C., had taken it upon itself to set a new metric practice standard.

So we tracked down Virginia Wilkening, leader of the Nutrition Regulations Unit in the Office of Food Labeling at the FDA, who said her department has received several comments on this very topic. She said the official position of the FDA, recorded in Vol. 58, no. 158, of the Federal Register, is that the agency "did not insist on a space on the nutrition labels to minimize the space taken by the information."

It does acknowledge, however, that "the preferred form of metric usage is to leave a space between the number and the symbol that refers to it," and that it "has no problem if a manufacturer decides to include the space."

More on political correctness

In response to our April column on this topic, Peter VandeMotte of New York City suggested that EEs are plagued by a fear of their own mortality. We had commented that the common (mis)pronunciation of *kilometer*, which accents the second syllable (*ki-lo'-me-ter*), is at odds with the SI-preferred pronunciation, which places the stress on the first syllable (*kil'-o-me-ter*).

"I believe the common pronunciation [which does not accent the sound *kill*] stems from the desire to avoid facing death or any term relating to it," wrote VandeMotte, pointing to the use of "No Outlet" instead of "Dead End" on street signs. He offers further evidence of our uneasiness with death-related topics: connections are often referred to as "points" rather than terminals, on which wires are "landed," not terminated. "Having been away from the television field," he adds, "I do not know the acceptable term for TV 'ghosts,'" another death-related term.

Technically Speaking sees a number of potentially correctable terms. The "kill-switch" would become "electrical euthanasia actuator," and "dead" memory devices would merely be victims of "bit attention deficit disorder" (BADD).

Juicy bits of jargon

As technical professionals, we come in for our share of criticism for generating jargon. All the same, we should at least stay current with the latest coinages. Here are a few recent examples, culled by Technically Speaking from several sources.

From the Jargon Watch column of the January 1994 issue of *Wired* magazine comes the term "mouse potato," described as "the on-line and interactive-TV generation's answer to the couch potato." With the proliferation of pointing devices for computers, we find ourselves pondering such other possibilities as "pen potatoes," "trackball tubers," and "stylus spuds."

The explosive growth of the multimedia industry has spawned its own lexicon. It has brought "seedy ROMs," for compact discs containing sexually explicit material. A recent program on Public Radio International's "Marketplace" program labeled haphazardly packaged, poorly written software on CDs as "shovelware," and claimed that such materials were leading a trend toward "multimedocrity."

From Microsoft Corp.'s brochure entitled "Focus on Microsoft Windows" comes "soft-lifting," an innovative take on the illegal sharing or pirating of software. It is curious that although the words *buccaneer* and *corsair* are synonyms for *pirate*, phrases such as *bit buccaneering* and *code corsair* never caught on.

Technically Speaking is intended as a commentary on the use and misuse of technical language and culture, both within the scientific/engineering community and by the general public. Comments, concerns, commendations, and condemnations will be accepted, often cheerfully. Readers are invited to reply by mail, care of Technically Speaking at IEEE Spectrum, or by e-mail to klsf@mcimail.com. Please indicate the city, state, and country you are writing from, as well as IEEE affiliation, if any.

Contributing editor Kevin Self (M) surveys the etymological world from his workbench at Dallas Semiconductor Corp., in Dallas, Texas.

CONSULTANT: Anne Eisenberg, Polytechnic University



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Calendar

(Continued from p. 17)

LEOS '94 (LEO); Oct. 31–Nov. 4; Sheraton Boston Hotel and Towers; Susan Evans, IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855; 908-562-3896; fax, 908-562-1571; e-mail, s.evans@ieee.org.

NOVEMBER

Third International Conference on

Software Reuse (C); Nov. 1–4; Hotel Othon, Rio de Janeiro, Brazil; William Frakes, Virginia Tech, Computer Science Department, Northern Virginia Graduate Center, 2990 Telestar Court, Falls Church, VA 22042; 703-698-6020; fax, 703-698-6062; e-mail, frakes@sarvis.cs.vt.edu.

Ultrasonics Symposium (UFC); Nov. 1–4; Hotel Martinez, Cannes, France; C. Maerfeld, Thomson Sintra, 1 ave. Aristide-Briand, 94117 Arcueil, Cedex, France; (33+1) 49 853 100.

Electron Devices Activities In Western

New York Conference (ED); Nov. 2; Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, New York; Sophie Verdonck-Vandebroek, Xerox Corp., J.C. Wilson Center for Research and Technology, 800 Phillips Rd., Building 114-41D, Webster, NY 14580; 716-422-9796; fax, 716-422-1035.

Electrical Performance of Electronic Packaging (CPMT, MTT); Nov. 2–4; Monterey Plaza Hotel, California; Paul A. Baltes, Engineering Professional Development, Box 9, Harvill Building, Room 235, 2nd and Olive Streets, Tucson, AZ 85721; 602-621-3054; fax, 602-621-1443.

European Topical Congress on Technologies for Wireless Applications (MTT); Nov. 2–5; New Linootto Fair Center, Via Nizza, Turin, Italy; P. W. Staecker, M/A-Com Inc., 100 Chelmsford St., Lowell, MA 01853-3294; 508-656-2607; fax, 508-656-2777; e-mail, p.staecker@ieee.org.

Frontiers in Education Conference—FIE '94 (E); Nov. 2–7; Fairmont Hotel, San Jose, Calif.; James Freeman, Engineering Department, San Jose State University, San Jose, CA 95192; 408-924-3806; fax, 408-924-3818; e-mail, jfreeman@sjsuvm.sjsu.edu.

Symposium on Advanced Research in Asynchronous Circuits and Systems (C); Nov. 3–5; University Park Hotel, Salt Lake City, Utah; Erik Brunvand, Department of Computer Science, University of Utah, Salt Lake City, UT 84112; 801-581-4345; fax, 801-581-5843; e-mail, Brunvand@cs.utah.edu.

16th International Conference (EMB); Nov. 3–6; Omni International Harbor Hotel, Baltimore, Md.; Steve Marlin, Meeting Management Inc., 2703 Main St., Suite 690, Irvine, CA 92714; 714-752-8205; fax, 714-752-7444.

12th International Conference on Computer-Aided Design (C, CAS); Nov. 6–10; Red Lion Hotel, San Jose, Calif.; MP Associates Inc., 5305 Spine Rd., Suite A, Boulder, CO 80301; 303-530-4562.

Workshop on Motion of Non-rigid and Articulate Objects (C); Nov. 11–12; Hotel Marriott at the Capital, Austin, Texas; J. K. Aggarwal, Department of Electrical and Computer Engineering, University of Texas, Austin, TX 78712-1084; 512-471-3259; e-mail, jka@emx.cc.utexas.edu; fax, 512-471-5532.

First International Conference on Image Processing—ICIP '94 (SP); Nov. 13–16; Austin Convention Center, Texas; Al Bovik, Department of Electrical and Computer Engineering, University of Texas, Austin, TX 78712-1084; 512-471-5370; fax, 512-471-5907; e-mail, bovik@cs.utexas.edu.

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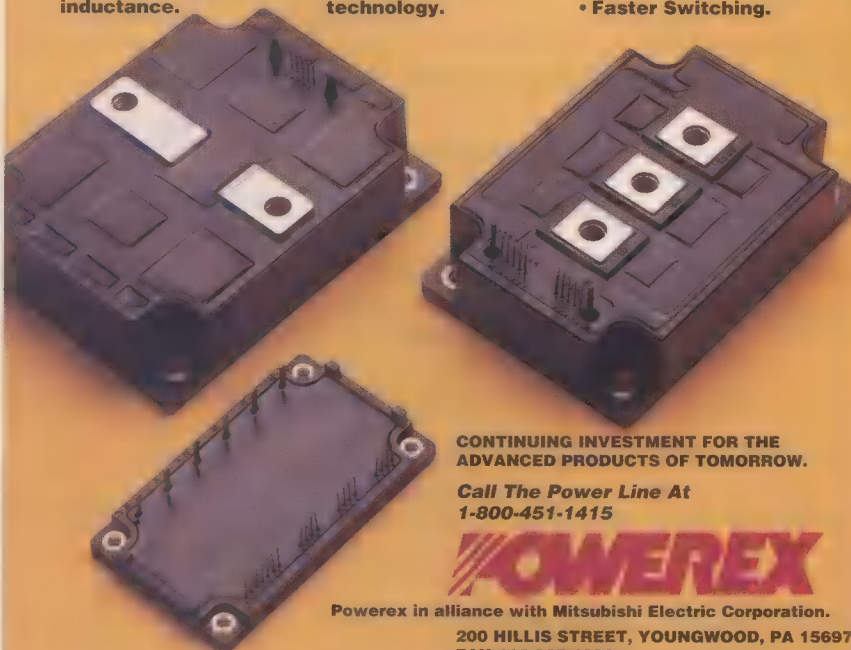
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(Continued from p. 18E2)

Workshop on High Performance Electron Devices for Microwave and Optoelectronic Applications (ED); Nov. 14; King's College London, the Strand; Ali A. Rezazadeh, Department of ECE, King's College London, London University, Strand, London WC2R 2LS, England; (44+71) 873 2879; fax, (44+71) 836 4781.

Third Workshop on Program Compre-

hension—WPC '94 (C); Nov. 14-15; Ramada Hotel, Falls Church, Va.; Vaclav Rajlich, Computer Science Department, Wayne State University, Detroit, MI 48202; 313-577-5423; fax, 313-577-6868; e-mail, vtr@cs.wayne.edu.

Advanced Semiconductor Manufacturing Conference and Workshop (ED); Nov. 14-16; Hyatt Regency Hotel, Cambridge, Mass.; Margaret M. Kindling, SEMI, 2000 L St., N.W., Suite 200, Washington, DC 20036; 202-457-9584; fax, 202-659-8534.

Topical Conference on the Synthesis

Japan; Masami Akaike, c/o Realize Inc., Cosmos Hongo Building, 4-1-4 Hongo, Burkyoku Tokyo 113, Japan; (81+3) 3815 8590; fax, (81+3) 3815 8939.

Semiconductor Interface Specialists Conference (ED); Dec. 7-10; San Diego Hilton, California; Robert E. Stalhush, IBM Thomas J. Watson Research Center, Room 29-113, Box 218, Yorktown Heights, NY 10598; 914-945-2837; fax, 914-945-2141.

Workshop on Mobile Computing Systems and Applications (C); Dec. 8-9; Dream Inn, Santa Cruz, Calif.; Darrell Long, Computer and Information Sciences, University of California, Santa Cruz, CA 95064; 408-459-2616; fax, 408-459-4829; e-mail, darrell@cse.ucsc.edu.

International Electron Devices Meeting (ED); Dec. 11-14; San Francisco Hilton & Towers; Melissa Widerkehr, Widerkehr and Associates, Suite 610, 1545 18th St., N.W., Washington, DC 20036; 202-986-1137; fax, 202-986-1139.

33rd Conference on Decision and Control (CS); Dec. 14-16; Buena Vista Palace at Walt Disney World Village, Orlando, Fla.; M. K. Masten, Texas Instruments Inc., 2309 Northcrest, Plano, TX 75075; 214-462-3433; fax, 214-462-3126.

Third International Workshop on Cellular Neural Networks and Their Applications—CNNA '94 (CAS, Region 8); Dec. 18-21; University La Sapienza, Rome, Italy; V. Cimagalli, Department of Electronic Engineering, La Sapienza University of Rome, via Eudossiana 18, Rome, Italy I-00184; (39+6) 4458 5836; fax, (39+6) 4742 647; e-mail, cima@tce.ing.uniroma1.it.

International Conference on Parallel and Distributed Systems (C); Dec. 19-21; National Chiao Tung University, Hsinchu, Taiwan; Lionel M. Ni, Department of Computer Science, Michigan State University, 714 Wells Hall, East Lansing, MI 48824-1027; 517-353-4386; fax, 517-336-1061; e-mail, ni@cps.su.edu.

First International Conference on Electronics, Circuits, and Systems—ICECS '94 (CAS); Dec. 19-22; Nile Hilton Hotel, Cairo, Egypt; Jenny Curry, Department of Electrical Engineering, Ohio State University, Columbus OH 43210; 614-292-3245; fax, 614-292-7596.

First International Conference on Software Testing, Reliability and Quality Assurance—STRQA '94 (Region 10, et al.); Dec. 21-22; Hotel Taj Palace, New Delhi, India; Aditya Mathur, Department of Computer Science, Purdue University, W. Lafayette, IN 47907; 317-

(Continued on p. 18E10)

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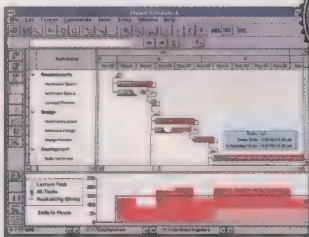
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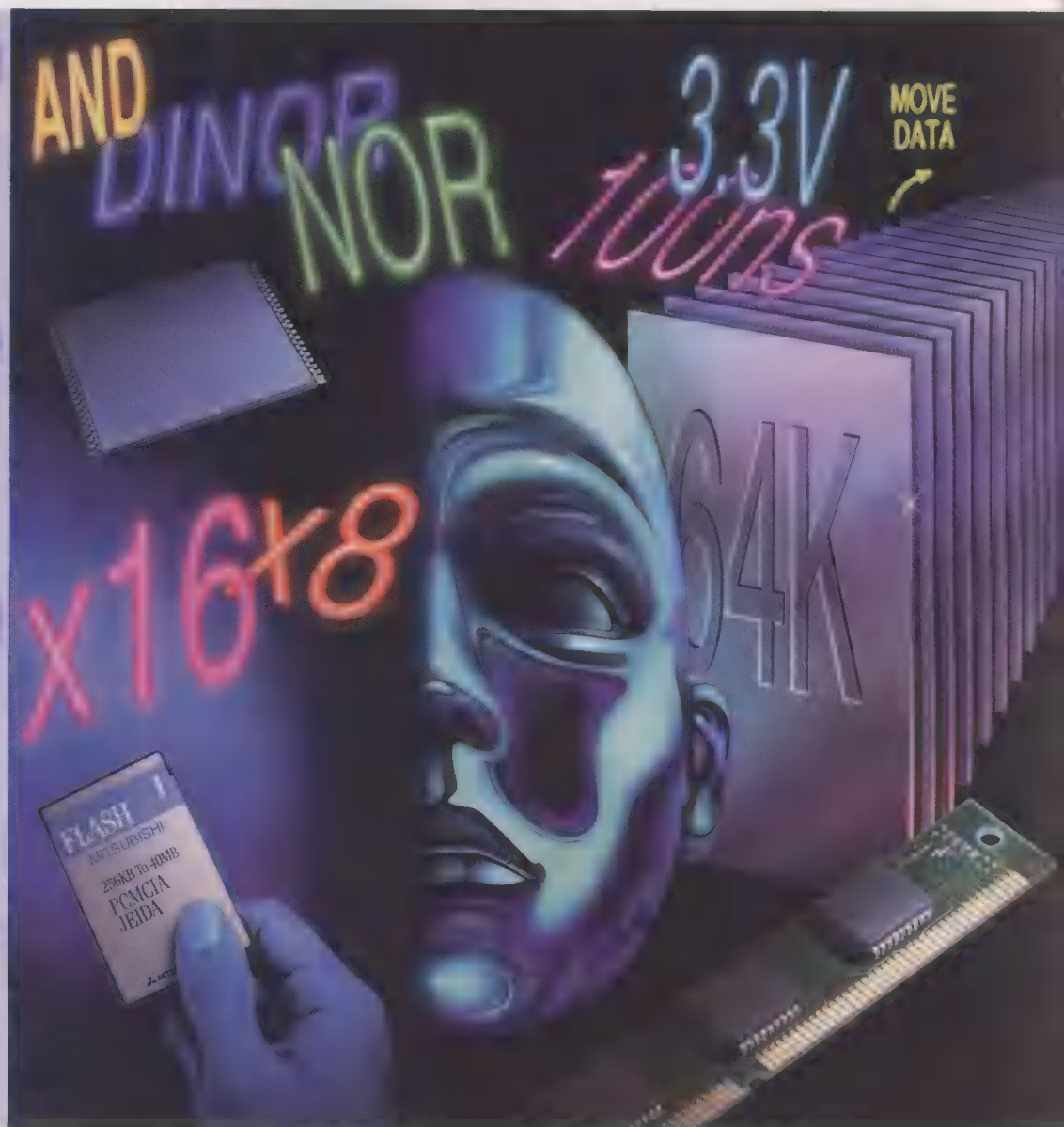
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Calendar

(Continued from p. 18E6)

494-6010; fax, 317-494-0739; e-mail, amp@cs.purdue.edu.

JANUARY 1995

Eighth International Conference on VLSI Design (C, CAS); Jan. 4-7; Hyatt Regency, New Delhi, India; Adit D. Singh, Department of EE, Auburn University, Auburn, AL 36849; 205-844-1847; fax, 205-844-1809; e-mail, adsingh@eng.auburn.edu.

Industrial Automation and Control—IA & C '95 (IA, et al.); Jan. 5-7; Krishna Oberoi Hotel, Hyderabad, India; E. Bhagiratha Rao, Engineering Staff College of India, Khairatabad, Hyderabad—500 004, India; (91+40) 229 666; fax, (91+40) 243 634.

10th Annual Battery Conference on Applications and Advances (AES, PEL); Jan. 10-12; California State University, Long Beach, Calif.; Renee Madrid, Department of EE, California State University, 1250 Bellflower Blvd., Long Beach, CA 90840-8303; 310-985-4605; fax, 310-985-7561.

Brazilian School of Microelectronics (ED); Jan. 15-20; Cidade Universitaria, Recife, Brazil; Edval J.P. Santos, Department de Fisica, University Federal de Pernambuco, Cidade Universitaria, 50670-901 Recife PE, Brazil; (55+81) 271 01 11; fax, (55+81) 271 03 59.

Reliability and Maintainability Symposium—RAMS (R); Jan. 17-19; Washington Hilton, District of Columbia; V.R. Monshaw, Consulting Services, 1768 Lark Lane, Cherry Hill, NJ 08003; 609-428-2342.

Conference on Wafer Scale Integration—ICWSI (C, CPMT); Jan. 18-20; Fairmont Hotel, San Francisco; Glenn Chapman, School of Engineering Science, Simon Fraser University, Burnaby, BC V5A 1S6; 604-291-3814; fax, 604-291-4951; e-mail, glenncc@cs.sfu.ca.

First Symposium on High Performance Computer Architecture (C); Jan. 23-26; Sheraton Inn, Raleigh, N.C.; E. W. Davis, Department of Computer Science, North Carolina State University, Box 8206, Raleigh, N.C. 27695-8206; 919-515-7045; fax, 919-515-7896; e-mail, davis@adm.scc.ncsu.edu.

Power Engineering Society Winter Meeting (PE); Jan. 29-Feb. 2; New York Hilton and Towers, New York City; Frank E. Schink, 14 Middlebury Lane, Cranford, NJ 07016-1622; 908-276-8847.

(Continued on p. 74E5)

Recent books

Formulas for Stress, Strain and Structural Matrices. *Pilkey, Walter D.*, John Wiley & Sons, New York, 1994, 850 pp., \$74.95.

Rightsizing the New Enterprise: The Proof, not the Hype. *Kern, Harris, and Johnson, Randy*, Prentice Hall, Englewood Cliffs, N.J., 1994, 326 pp., \$38.

Creativity in Invention and Design: Computational and Cognitive Explorations of Technological Originality. *Dasgupta, Subrata*, Cambridge University Press, New York, 1994, 250 pp., \$39.95.

Internetworking with TCP/IP, Vol. II: Design Implementation and Internals. *Comer, Douglas E., and Stevens, David L.*, Prentice Hall, Englewood Cliffs, N.J., 1994, 613 pp., \$50.

Transient Stability of Power Systems: Theory and Practice. *Pavella, M., and Murthy, P.G.*, John Wiley & Sons, New York, 1994, 403 pp., \$98.

Image Processing, Analysis and Machine Vision. *Sonka, Milan, et al.*, Chapman & Hall, New York, 1994, 555 pp., \$39.95.

McGraw-Hill Concise Encyclopedia of Science and Technology, 3rd edition. Ed. *Parker, Sybil P.*, McGraw-Hill, New York, 1994, 2241 pp., \$115.50.

Windows Animation with C++ Programming. *Young, Michael J.*, Academic Press, San Diego, Calif., 1994, 303 pp., \$39.95 (diskette included).

Programmable Controllers: Hardware, Software and Applications, 2nd edition. *Batten, George L., Jr.*, McGraw-Hill, New York, 1994, 285 pp., \$39.

Engineering Design: A Synthesis of Views. *Dym, Clive L.*, Cambridge University Press, New York, 1994, 205 pp., \$49.95 (hardcover), \$19.95 (paperback).

The United States, Japan and Asia: Challenges for U.S. Policy. Ed. *Curtis, Gerald L.*, W. W. Norton, New York, 1994, 288 pp., \$28.

Automatic Control of Converter-Fed Drives. *Kazmierkowski, M.P., and Tunia, H.*, Elsevier Science Publishing, New York, 1993, 576 pp., \$200.

The Infrared and Electro-Optical Systems Handbook: Vols. 1-8. Eds. *Accetta, Joseph, and Shumaker, David*, ERIM, Ann Arbor, Mich., and SPIE, Bellingham, Wash. (Vol. 1: Sources of Radiation, 373 pp.; Vol. 2: At-

mospheric Propagation of Radiation, 322 pp.; Vol. 3: Electro-Optical Components, 666 pp.; Vol. 4: Electro-Optical System Design, Analysis & Testing, 352 pp.; Vol. 5: Passive Electro-Optical Systems, 355 pp.; Vol. 6: Active Electro-Optical Systems, 312 pp.; Vol. 7: Countermeasure Systems, 508 pp.; Vol. 8: Emerging Systems & Technologies, 636 pp.); 1994, \$275 (the set).

Digital Signal Processing in Telecommunications. Eds. *Westall, F.A., and Ip, S.F.A.*, Chapman & Hall, New York, 1994, 486 pp., \$95.

E-mail Essentials. *Tittel, Ed, and Robbins, Margaret*, Academic Press, New York, 1994, 298 pp., \$24.95.

Magnetostatic Waves and Their Applications. *Kabos, P., and Stalmachov, V.S.*, Chapman & Hall, New York, 1994, 303 pp., \$90.50.

Multimedia: Gateway to the Next Millennium. Eds. *Aston, Robert, and Schwarz, Joyce*, Academic Press, New York, 1994, 287 pp., \$39.95.

Microsoft Project 4 For Windows: Step by Step. *Catapult Inc.*, Microsoft Press, Redmond, Wash., 1994, 368 pp., \$29.95.

Electrical Safety: A Guide to the Causes and Prevention of Electrical Hazards. *Adams, J. Maxwell*, IEEE/INSPEC, Piscataway, N.J., 1994, 194 pp., \$75.

Distributing Applications Across DCE and Windows NT. *Rosenberry, Ward, and Teague, Jim*, O'Reilly & Associates, Sebastopol, Calif., 1994, 302 pp., \$24.95.

Stochastic Processes, 2nd edition. *Medhi, J.*, John Wiley & Sons, New York, 1994, 598 pp., \$39.95.

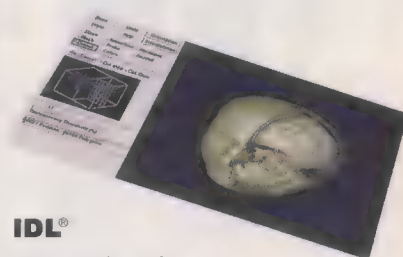
Problems and Solutions in Electronics. *Loxton, Roger*, Chapman & Hall, New York, 1994, 250 pp., \$24.95.

Engineer's and Manager's Guide to Winning Proposals. *Helgeson, Donald V.*, Artech House, Norwood, Mass., 1994, 219 pp., \$49.

Understanding DCE. *Rosenberry, Ward, et al.*, O'Reilly & Associates, Sebastopol, Calif., 1994, 266 pp., \$24.95.

Protective Relaying Theory and Applications. *ABB Power T&D Co.*, Marcel Dekker, New York, 1994, 376 pp., \$99.75.

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Recent books

Vacuum Switchgear. Greenwood, Allan, IEE/INSPEC, Piscataway, N.J., 1994, 278 pp., \$95.

Microwave Integrated Circuits. Eds. Kneppo, I., and Fabian, J., Chapman & Hall, New York, 1994, 329 pp., \$99.95.

Coping with Chaos: Analysis of Chaotic Data and the Exploitation of Chaotic Systems. Eds. Ott, Edward, et al., John Wiley & Sons, New York, 1994, 418 pp., \$47.95

Bistabilities and Nonlinearities in Laser Diodes. Kawaguchi, Hitoshi, Artech House, Norwood, Mass., 1994, 379 pp., \$88.

Guide to Writing DCE Applications, 2nd edition. Shirley, John, et al., O'Reilly & Associates, Sebastopol, Calif., 1994, 462 pp., \$29.95.

Maple V Quick Reference. Blachman, Nancy R., and Mossinghoff, Michael J., Brooks/Cole Publishing, Pacific Grove, Calif., 1994, 522 pp., \$26.25.

Methods and Tools for Applied Artificial Intelligence. Popovic, Dobrivoje, and Bhatkar, Vijay P., Marcel Dekker, New York, 1994, 528 pp., \$150.

Principles of Signaling for Cell Relay and Frame Relay. Minoli, Daniel, and Dobrowski, George, Artech House, Norwood, Mass., 1995, 305 pp., \$77.

Digital Image Processing Methods. Ed. Dougherty, Edward R., Marcel Dekker, New York, 1994, 504 pp., \$150.

Shop Floor Control Systems: From Design to Implementation. Bauer, A., et al., Chapman & Hall, New York, 1994, 344 pp., \$43.

Chaos in Wonderland: Visual Adventures in a Fractal World. Pickover, Clifford A., St. Martin's Press, New York, 1994, 302 pp., \$29.95, \$41.50 (CAD).

Soft Computing: Fuzzy Logic, Neural Networks, and Distributed Artificial Intelligence. Eds. Aminzadeh, Fred, and Jamshidi, Mohammad, Prentice Hall, Englewood Cliffs, N.J., 1994, 301 pp., \$65.

An Inventor in the Garden of Eden. Laithwaite, Eric, Cambridge University Press, New York, 1994, 289 pp., \$24.95.

Advances in Genetic Programming. Ed. Kinnear, Kenneth E., Jr., MIT Press, Cambridge, Mass., 1994, 518 pp., \$45.

Activity Costing for Engineers. Innes, John, et al., John Wiley & Sons, New York, 1994, 154 pp., \$69.95.

SPARC Architecture, Assembly Language Programming, & C. Paul, Richard P., Prentice Hall, Englewood Cliffs, N.J., 1994, 448 pp., \$45.

Information Systems Engineering: A Formal Approach. Van Hee, K.M., Cambridge University Press, New York, 1994, 421 pp., \$44.95.

Electrogastrography: Principles and Applications. Eds. Chen, Jiande Z., and McCallum, Richard W., Raven Press, New York, 1994, 447 pp., \$90.

Advances in Electrochemical Science and Engineering, Vol. 3. Eds. Gerischer, Heinz, and Tobias, Charles W., VCH Publishers, New York, 1994, 250 pp., \$120, \$95 (subscription).

(Continued on p. 74T4)

Washington watch

Defense to favor readiness above new arms purchases

The Pentagon recently ordered the preparation of plans to cancel or delay major arms systems still in development by the Army, Navy, and Air Force.

The decision to prefer military readiness over modernization was necessitated by a tight budget and the fact that many development programs of the 1980s are now reaching their expensive final procurement stage. With painful memories of the unprepared military of the late 1970s, neither Congress nor the Pentagon is about to sacrifice funds for training and operations.

In July, the U.S. General Accounting Office estimated the Pentagon may come up \$150 million short in its \$1.2 trillion budget for 1995-99, a result of having overstated savings and underestimated costs.

The order, conveyed in a two-page memo from Deputy Secretary John M. Deutch in August, asks the services to consider changes in 10 programs, including:

- Canceling the Army's new Comanche scout helicopter, a project of Boeing Co. and the Sikorsky division of United Technologies Corp.
- Canceling the Marine Corps' V-22 Osprey tiltrotor aircraft, which is being developed by Boeing and Bell Helicopter Textron Inc.
- Canceling the Tri-Service Standoff Attack Missile of Northrop Grumman Corp.
- Postponing by up to four years the initial purchase of 422 F-22 fighter aircraft, built by Lockheed and Boeing.
- Postponing the rate of production of destroyers built at shipyards in Maine and Mississippi and of the new attack submarine from the Electric Boat Division of General Dynamics.

Japan patents entente cordiale

U.S. inventors should benefit from an August agreement signed by U.S. Commerce Secretary Ronald Brown and Japanese ambassador Takakazu Kuriyama. The inventors should as a result be better protected and their applications processed faster.

The Japanese Patent Office agreed to end three of its practices. As of April 1, 1995, it will no longer allow third parties to oppose a competitor's patent before it is granted. By July, it will cease awarding "dependent patent compulsory licenses," which can force patent holders to license the use of their technology to competitors, thus limiting exclusive rights to their in-

vention. And as of January 1996, an accelerated patent examination procedure will let applicants obtain disposition of their applications within 36 months upon request.

The agreement requires the U.S. Patent and Trademark Office to publish pending patent applications 18 months after filing, starting with those filed after Jan. 1, 1996,

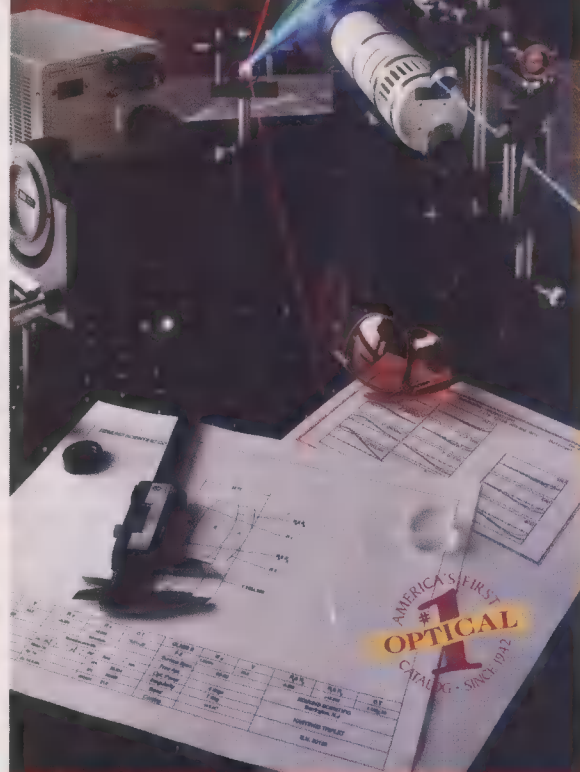
and to expand reexamination proceedings to allow greater participation by third parties.

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Washington watch

National Standards Institute recently signed an agreement to develop the National Standards Systems Network together. Its goal: to link the databases of hundreds of U.S. organizations (including the IEEE) involved in developing, producing, distributing, and using technical standards.

To be up and running in five years, the network will provide cataloging, indexing, searching, and routing with access to all regional, national, and international standards.

The project is seen as slashing standards development time and costs. It should also minimize duplication of standards, increase standards dissemination to small businesses, and enhance involvement in national and international standards activities. It is funded by a grant from the government's Technology Reinvestment Project.

For more details, contact David Cranmer, B115 Polymer Bldg., NIST, Gaithersburg, Md. 20899-0001, 301-975-5753; e-mail, cranmerd@nml.nist.gov.

Reinventing government

Despite some "impressive results," Vice President Albert Gore's initiative to "rein-

vent government" has undercut its own chances of long-term success, said a study by the Brookings Institution here.

The successes include a "major reform of the government's contracting rules, an effort to better coordinate Federal management," and the establishment of four principles—cutting red tape, putting customers first, empowering employees to get results, and returning to basics—to guide government bureaucrats.

One of the obstacles to long-term success is the lack of a strategy for winning congressional support. Moreover, though the biggest savings are to come from cutting the number of Federal employees, no analysis has been done of whether the downsizing would shrink government in the right places.

Policies for EEs

Information on the IEEE's government relations policies is available to electrical engineers through the Internet. Included is the IEEE-U.S. Activities Legislative Report (info.ieeeusa.legprpt@ieee.org), a chronological log of IEEE-USA testimony and communications with public policymakers (info.ieeeusa.policy@ieee.org), and a list of position statements (info.ieeeusa.pos@ieee.org). To obtain these files, send an e-

mail request via Internet: no subject line or text message is required. For more information, contact Chris Brantley by e-mail (c.brantley@ieee.org) or by voice in Washington, D.C., at 202-785-0017.

Metric plea, again

Continuing its metric campaign, the U.S. National Institute of Standards and Technology sounds almost frustrated and impatient in a new report by Gary Carver, a physical scientist in the Manufacturing Engineering Laboratory.

"The metric system cannot be avoided in international trade and commerce," Carver states. "It will be interesting to see how long the United States can hold out against the worldwide use of the International System of Units, the modern metric system. What is even more curious is why would the world's leading industrial nation want to resist using a world standard?"

The report, "A Metric for Success," discusses metric trends and the history and the role of the Commerce Department in the transition to the metric system. Copies of NISTIR 5425 are available for the asking at 301-975-3690; fax, 301-948-1416.

John A. Adam Washington Editor

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Graphics

An eye-popping summer

Since making a splash with the watery, strangely goofy extraterrestrial in the 1989 motion picture *The Abyss*, computer-generated imagery and special effects have figured memorably in a number of films—the morphing of *Terminator 2* in 1991 and the dinosaurs of last year's *Jurassic Park* come to mind. But the summer of 1994 will surely go down as the time when Hollywood's flirtation with digital effects turned into a flamboyant love affair.

Movie after movie dazzled with effects, which in kind and quantity had never quite been seen before. In *Forrest Gump*, actor Tom Hanks was convincingly inserted into a variety of vivid panoramic and historical scenes, as well as into ceremonies with no fewer than three U.S. presidents. In *The Flintstones*, actors appeared to bestride natural-looking dinosaurs, and the family pet, Dino, was entirely computer generated. *True Lies*, a comedy thriller, had leading man Arnold Schwarzenegger flying ■ Harrier jump-jet in one of the more tense family outings in recent memory. And in *The Mask*, the green title object turns a wonkish bank clerk into a grinning, jive-talking, eye-popping, jaw-dropping chimera familiar to anyone who has ever seen the classic U.S. cartoons of the 1940s, '50s, and '60s (see photo, above).

"We now have the ability to create 'real' characters, and 'real' story elements, using effects," said Stephen Gray, vice president of technology at Digital Domain, a motion-picture production and special effects company in Venice, Calif. "There are pictures in production now where the central element is effects. Characters, or embellishments on characters, are so photorealistic that they blend into the picture."

Of the past summer's releases, *The Mask* stands out for its bald confirmation that digital imagery and effects have become integral to an expanding group of mainstream Hollywood movies, most of which would be unexceptional or even pointless without the digital assist. "*The Mask* is not so much a movie, more a feature-length demo reel for the wonders of digital conjuring on screen," wrote film critic Nigel Andrews in *The Financial Times*. "You end up enthused by the product but wondering, before you take out your cheque book, whether you should not wait a little longer while they improve the story-packaging."

Moviegoers and most other critics were not so demanding, however, auguring no letup in effects-stuffed films and in ever-more astounding effects. "In the past, it was the science and engineering markets who would



be really the ones who were pushing us, but now, more often than not, it's the entertainment community, and the science and engineering communities are benefiting from the advances," said Greg Estes, product line manager in the advanced graphics division at Silicon Graphics Inc. in Mountain View, Calif. The company reckons it has nine-tenths of the market for the hardware used to create three-dimensional effects in film and video.

Most of the effects in all but one of the movies mentioned here were the work of Industrial Light & Magic (ILM) in San Rafael, Calif., the world's largest company devoted to visual effects. The exception is *True Lies*, whose effects were the work of the recently formed Digital Domain, owned by IBM in partnership with the film director (and former engineering student) James Cameron and others. (ILM itself is a division of Lucas Digital Ltd. in Nicasio, Calif.) Between them, ILM and Digital Domain account for a substantial portion of the computer-generated effects in big-budget Hollywood motion pictures.

ILM is linked to Silicon Graphics through a Joint Environment for Digital Imaging, which an ILM spokesperson described as "an arrangement by which we get a lot of equipment, especially before it's available in the marketplace. The name of the game is processing power. That's the hurdle standing in the way of more and more intricate effects." Tom Williams, the executive in charge of digital effects at ILM, noted that moviemakers "keep raising the bar in terms of what audiences see." So, despite great leaps in processing power, the time needed to render ■ frame appears to be holding constant at about an hour.

To date, ILM has accumulated 140 Silicon Graphics machines, "but by the end of the year it will be more like 180," the ILM

spokesperson said. Ranging from desktop systems to top-of-the line Onyx graphics workstations and ■ 36-processor Challenge "super" server, ILM's arsenal is probably the most powerful ever assembled in the entertainment world.

Digital Domain is not far behind, though, with its own growing collection arrayed in a "multi-tiered environment," according to Stephen Gray. The arrangement is consistent with the company's mission, to be "a facility where directors can have ■ more interactive experience in creating their films," Gray explained. Thus, an assortment of low- and very high-end platforms are used for approximating and previewing two- and three-dimensional effects—"to allow directors to come in and see how effects will look...to give them ■ feel for the nature of the effects," Gray said. For economy, the effects themselves are created on mid-range workstations, like Silicon Graphics' US \$50 000 Indigo2 Extreme Graphics.

As for software, both ILM and Digital Domain use a mix of their own and commercially available packages, the latter particularly to accomplish four of the fundamental steps that go into ■ typical special effect: modeling, animation, painting, and rendering. In modeling, the shape and structure of the objects to be seen on screen are conjured up; for this ILM uses software from Alias in Toronto. For animation, in which the seeming objects are induced to move and otherwise brought to life, the company uses a program from SoftImage in Montreal. To paint, or color, the objects and images, ILM uses Matador, from Parallax Software Inc., London. Rendering, in which the completed image is drawn on the screen, is done with RenderMan, written by one of ILM's predecessor companies but now enhanced and sold by

Pixar in Point Richmond, Calif.

One secret of ILM's success, however, is a large amount of in-house software. This is used for, among other things, compositing, a critical step in which images are combined into one sequence; it might involve the insertion of computer-generated animations into conventionally filmed ("live action") footage, say, or the combination of images from different live-action scenes, or both.

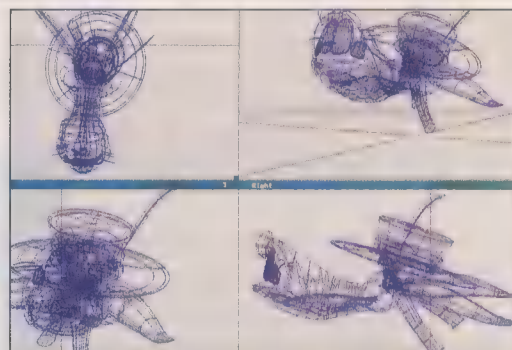
ILM's own software also extends its abilities in modeling and animation. Programs for boosting the realism of flesh, muscle, tissue, and underlying biomechanical details were used to model and animate the hides of dinosaurs in *Jurassic Park* and *The Flintstones* and the wildly expressive visage of protagonist Stanley Ipkiss in *The Mask*. Still other proprietary software is used to finely adjust and correct lighting and texture during rendering.

Williams and others see the fruits of all this feverish programming going in two distinct directions: "invisible" vs. "zany" effects. The first are designed to be indistinguishable from live action, as exemplified by most of the effects in *Forrest Gump* and also *True Lies*. The second include *The Mask's* and *The Flintstones'* variety, which depict things that are obviously well outside the bounds of reality but delight audiences with their outrageousness, cleverness, and/or verisimilitude.

The first group, in particular, relies heavily on sophisticated, state-of-the-art compositing. The three-minute-long opening shot of *Forrest Gump*, in which a feather suggests a unifying theme by twisting, darting, and gliding at the mercy of serendipitous breezes, was a masterpiece of compositing and to date the most prolonged computer-graphics effect ever accomplished at ILM. "There's a certain beauty in the simplicity of that shot," said Williams.

A real feather was filmed on a set against a blue-screen background (the color is chosen so as to be readily removed during compositing). Meanwhile, actor Tom Hanks was filmed sitting on a bench, including some close-ups showing an identical, second, feather at his right foot. (This look-alike feather was necessary because Hanks picks it up at the end of the sequence.) In compositing, the first (blue-screen) feather was added to the live action. The feather at Hanks' foot, meanwhile, was painted out of the scene until the end, at the instant when the first feather "lands" there—visually becoming the feather at Hanks' foot [see photos, opposite page].

Although compositing was the basic tech-



A cartoonish wolf's head is the inevitable result of laying eyes on a comely torch singer in *The Mask*. The complex effect required modeling and animation of the head, and compositing to "remove" actor Jim Carrey's head and replace it with the wolf's.

nique that made the whole sequence possible, others were required for the details that turn the final, composited and rendered footage into something virtually indistinguishable from conventionally filmed live action. For example, the first feather had to be "lit" just like everything in the live action, and also had to cast the correct shadow on Hanks as it drifted in front of him.

For these details, ILM's programmers [IEEE Spectrum is pleased to eschew the term "wizards"] relied on techniques in which a computer determines key lighting and focal aspects of a shot, and ensures that all the composite elements in the final shot conform to them. The "computer-camera" technique, first used for effects in *Jurassic Park*, in effect matches the computer imagery to the geometry, angle, and focal characteristics of the related live action. The process takes established reference points and objects visible in the live action—furniture, and so on—and from them deduces the angle of the camera, its optics, and other key parameters. "If you have enough points, it's a fully constrained problem, so you know there's only one way the camera could have gotten that image," Williams explained.

Though intriguing for its duration and sim-

licity, the feather sequence was only the beginning of what ILM did for *Gump*. Also generated by computer were: crowds in a football stadium and at ping-pong matches (and even the ping-pong balls); attack jets, explosions, and bullet tracers in a harrowing war scene; a flock of birds that takes off, as if on cue, when a little girl is praying behind her house; most of the sunsets, and many of the rainstorms. In the most talked-about effects, Hanks appears to meet and converse briefly at various times with three former U.S. presidents, John Lennon, and the talk show host Dick Cavett. In another marvel of compositing, the images of the legs of actor Gary Sinise were removed for scenes in which he appears as an amputee.

Extensive compositing was also needed to create the final scenes of *True Lies*, in which Arnold Schwarzenegger, thanks to Digital Domain, appears to use a hovering Harrier to rout terrorists from a skyscraper's upper floors. Scenes depicting the actor in a full-size Harrier on a motion base, with the wind blowing his hair, against a green (rather than blue) matte background, were filmed separately from shots of a crowd of people on the ground, which had to be distorted to simulate the exhaust from the jet. Other effects simulated the depth of field and perspective of a

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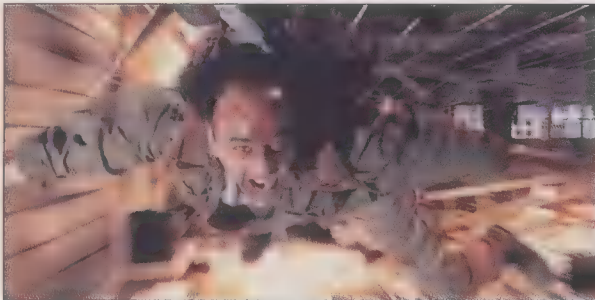
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In the motion picture True Lies, several sequences, beginning with an actor standing atop a green background, were digitally composited and the green color removed to make it look as if a terrorist was launched while dangling from an air-to-air missile.

camera's lens. To pull the whole thing together, Digital Domain used its own compositing software, plus packages called Flame, from Discrete Logic Inc. in Montreal, and Video Composer, from Wavefront Technologies in Santa Barbara, Calif.

In another notable sequence in the movie, jet pilots appeared to fire missiles at bridges in the Overland Highway connecting Florida's keys. It required modeling and animating the missiles and also their smoke—always a problem. It was solved in this case with the particle-animation capabilities of a package called Prisms, from Side Effects Software Inc. in Toronto.

While compositing of course matters in a movie like *The Mask*, such a film's outré creations are more a testament to modeling and animation and the human imagination behind it all. *The Mask* aimed its cartoonish contortions and distortions at pleasing baby boomers raised on technicolor mayhem, and a fairly typical scene revolved around the transformation of the hero's head into a wolf-caricature. Here, compositing was used not only to remove the image of actor Jim Carrey's head, but also to reinstate any background objects that were originally blocked as his head moved but that would be visible when the wolf head was on his shoulders [see photos, p. 20].

The wolf head itself was first modeled with a "wire frame" to gain a quick, approximate idea of how it would move. Then the head was fleshed out, as it were, and animated, painted, and composited into the live action scene atop Carrey's shoulders. Finally, the entire image was rendered.

The filming of the live action for such scenes presented unusual challenges. For example, when the script called for the wolf character to kiss his fingers in appreciation, Carrey had to take the long snout

into account, since the wolf's lips were somewhere out in center field compared to his own. But the actor's uncanny ability to mimic cartoon beasts reduced the need for any serious visual touching-up. "Jim Carrey was probably the best actor we could have hoped for," said Williams. "He probably saved a fortune in special effects."

Perhaps surprisingly, despite all its visual mayhem, *The Mask* had significantly fewer special effects than *Forrest Gump*. With over 180 shots, or separate bits of screen footage, occupying just over 22 minutes of screen time, *Gump*'s digital effects are the most extensive in a Hollywood film to date. *The Mask* had about 80 shots lasting roughly 10 minutes—still more than *Jurassic Park* (60 shots, 6.5 minutes), *Terminator 2* (less than 5 minutes), and *The Abyss* (less

than 1 minute). As for how long this means people had to sit in front of workstations, *Jurassic Park*'s effects occupied the attention of about 50 ILM staffers on and off for about a year and a half.

Digital Domain now has two feature films in production, *Apollo 13*, directed by Ron Howard, and *Strange Days*, which Gray described as "kind of sci-fi, grunge, postnuclear, horror; it's got a little bit of everything in there." Of the two, *Apollo 13* will be the more effect-laden, with perhaps as much as 15 minutes' worth. "I hope no one thinks there are any effects in it at all," Gray said. At the same time, the company has launched "an internal R&D effort to do photorealistic, humanoid characters using motion-capture and advanced 3-D animation and rendering," and has bid on various movie projects "involving either computer-graphics-generated characters central to the entire film, or in which 3-D computer graphics helps tell the story," Gray disclosed.

With more people and more workstations, and a moviegoing public ravenous for special effects, the time devoted to special effects will go up. A movie based on the "Casper the Friendly Ghost" cartoon, with effects by ILM, is currently being produced by Steven Spielberg for release next year. It will have in the region of 400 special-effects shots occupying around 35 minutes of screen time.

"Casper is our next step," said Williams. "We will be getting more involved in creating protagonists and antagonists that exist throughout the movie" (as in *The Mask*).

"In a way," he added, "'visual effects' is going to become an antiquated term in the next three or four years. It will be just another set of tools the filmmaker uses."

Glenn Zorpette



A so-called invisible effect is meant to be indistinguishable from live action. In the movie Forrest Gump, for example, a three-minute-long opening shot follows a feather that floats through the city of Washington, D.C., and lands on Gump's shoetop. A real feather was shot against a blue background, which is then digitally replaced by the street scenes.

TEXAS



In 1808, Don Felipe Roque de la Portilla and 51 others reached their settlement in Texas. But not before their cattle and horses were stolen by rustlers, supplies were swept away by June floods and the cook ran off with an Indian squaw.

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By communicating through his large-screen TV set, Dave Ward can open windows, check entryways, unlock doors, and watch his favorite TV programs. For the first time since an accident paralyzed him in 1977, he has also gained enough control through technology to go outdoors on his own or read a book (on CD ROM) without assistance. Multiple technologies used at the Future Home Institute in Baltimore, Md., have been his liberating agents.

Technology combats disabilities

Technology can circumvent some biological impediments, but much work remains for rehabilitation engineers

In this issue, IEEE Spectrum begins a series of articles on engineering accomplishments for the common good—efforts that show how electrotechnology is being used in the service of mankind. Among the areas to be covered are physical disabilities, education, food development, and security.

Our first focus is on advances in equipment that offset physically functional limitations. In "Technology combats disabilities" [pp. 24-26], we discuss how disabled and elderly people are using aids that enhance mobility (walking a certain distance, lifting a weight, or climbing stairs) as well as sensory faculties (seeing print, hearing conversation, and speaking intelligibly).

In "Advancing step by step" [pp. 27-31], we examine how electrical stimulation is being used to help mobility. Although present experimental systems are far from restoring the normal use of one's legs, they

John A. Adam Senior Associate Editor

could extend the range and independence of wheelchair users.

Other articles in the series on technology and the disabled will examine such topics as cochlear implants for the deaf, navigation systems for the blind, robotic-assistive devices, and artificial speech generation. —Ed.

Most people, if they live long enough, will become disabled. Millions already—whether by birth, or through illness or accident—have physical limitations that affect their mobility or their ability to see, hear, or speak.

Fortunately, helping to overcome such difficulties are advances in technology that now allow computers to supply information for impaired senses and for controlling limbs and other bodily functions. As a result, people who are deaf, blind, or confined to a wheelchair are integrating into society as never before.

"Technology is increasing their indepen-

dence—in some cases, making them totally independent—and opening up job opportunities," observed speech and language pathologist Gail Pickering, who works for the Office of Disabled Student Services at the California State University, Northridge.

That boost to self-reliance has largely resulted from two trends. One is the eagerness with which people have accepted the Information Age. The text and graphics basis of computer networks disregards disabilities like deafness or lack of speech. With the emergence of electronic mail as a conversation equivalent, access to many kinds of interaction and even employment is possible from anyone's home.

The second trend is the development of more powerful tools for people who are disabled. Much has changed since the early 19th century invention of Braille. In the last few decades, work along all fronts has taken off. Engineers, with disabled people in mind, are designing products ranging from robotic devices to virtual reality interfaces. Examples include an apparatus that helps those suffering from



strokes to lift objects, large vocabularies of accessible synthetic voice that aid people with speech impediments, and more capable wheelchairs.

The multidisciplinary field is known as rehabilitation engineering. In any previous age, the attainment of its loftiest goals would have been called a miracle—to give sight to the blind, hearing to the deaf, speech to those who cannot talk, and mobility to the paralyzed. Nonetheless, despite the enormous strides made in the last 20 years, “the present level of available functional restoration still pales in comparison to the capabilities of nondisabled individuals,” said Charles J. Robinson, chairman of the department of rehabilitation, science, and technology at the University of Pittsburgh. He is also editor of the *IEEE Transactions on Rehabilitation Engineering*.

A more modest goal in rehabilitation engineering is to develop products and aids from which individuals can select. Some items substitute for biological systems, such as cochlear implants for hearing; but more often today, they are assistive technologies with which people can work around biological impediments.

Users like variety, commented Lawrence Scadden, senior program director of the National Science Foundation’s Persons with Disabilities Program. For one application, a blind person might prefer to use a speech-generating computer, and for another, refreshable Braille output, which can be read at over 250 words a minute.

GROWING MARKET. Definitions of disability vary. The U.S. Census Bureau states that 49 million people—nearly one-fifth of the U.S. population—are in some way disabled; nearly half—24.1 million—have a severe disability, in which a physical shortfall is coupled with a mental illness like Alzheimer’s disease. About 37 million persons in the United States over the age of 15 are affected by functional limitations (the focus of this series), according to an analysis by Irving K. Zola in the *Journal of Disability Policy Studies* (Vol. 4, no. 2, 1993).

Changing demographics will add to the latter group. In the United States alone, the 1990 census counted more than 31 million people aged 65 or older, comprising 13 percent of the adult population. In 1980, this age group was 11 percent of a smaller total. In another decade and a half, the percentage is likely to start rising steeply as the post-World War II Baby Boomers reach retirement age.

With suitable technological assistance, these elderly men and women may prolong their independence and reduce or postpone their need for specialized care. Their quality of life may be improved and the costs of their health care reduced.

Products originally designed for persons

with disabilities have sometimes proved useful to the able-bodied as well. The typewriter was intended for blind users, and the telephone resulted from Alexander Graham Bell’s work for the deaf. More recently, disabled persons have helped develop speech-recognition technology, although the initial research was targeted for fighter pilots, according to Susan Brummel, director of the Clearinghouse on Computer Accommodation of the U.S. General Services Administration, Washington, D.C.

Attacking barriers in multiple ways opens up new possibilities for everyone, said Brummel, who believes information should not be limited to a single means of output.

For individuals with disabilities, an extra choice of output may be vital. For society in general, an array of choices offers convenience and flexibility. Citing electronic mail, Brummel asked rhetorically, “Who would have thought typing words would be preferred to the telephone?” Similarly, the augmentation of visual information by speech systems can be handy for car drivers as well as for blind persons.

Closed captioning on television was developed for the hard of hearing, but is also being used to teach English as a second language and better speech to the semiliterate, observed Dinah Cohen, director of the Computer Electronic Accommodations Program at the Defense Medical Systems Support Center, Alexandria, Va. Voice-recognition systems may do as much for persons whose hands are occupied as for those with paralyzed limbs. They can also be used in data entry to reduce the number of keystrokes needed, and hence the incidence of repetitive strain injuries, noted Brummel.

MULTIPLE ACCESS. Multiple modes of access are stirring interest as a possible feature of more consumer products. This news could cheer not only the disabled but anyone who has encountered trouble in programming a videocassette recorder.

“We’ve been pretty passive in taking what’s been pushed our way,” Brummel said. “People have been accommodating the technology rather than vice versa.”

Ease of access to consumer products is not covered by the 1990 Americans with Disabilities Act, which prohibits discrimination against the disabled in almost everything else—employment, public services, accommodations, transportation, and telecommunications. But some companies, under the aegis of the Electronic Industries Association (EIA), Washington, D.C., are looking at designing accessibility into general products right from the start. The effort is driven by market demographics (notably the aging Baby Boomers) and the desire to anticipate Government mandates.

Products that give accessibility to the disabled and elderly may also make life easier

for the general population, according to acting director Timothy Farr of the technology applications program of the Electronic Industries Foundation (EIF), an EIA offshoot. Participating companies in the nascent EIF project include AT&T, Thomson, and Matsushita.

“You can’t design a product that every single person in the world can use,” Farr conceded. “But the intent is to maximize the potential.” The goal is to make products simpler and easy to use. Farr envisions computers with voice output commonly being purchased in the general market. Stereos will have larger readouts as well as voice output. The incremental costs of many functional redundancies of this nature, if planned during the design stage, would be marginal, Farr believes. Computing advances will continue to expand functionality at lower costs.

The EIF effort, which Farr expects to be in full swing within a few years, would confer a sort of EIA label of accessibility on consumer products. Optional cassettes might be available at stores for those who cannot read the manual. Various icons would indicate accessibility in any combination of seven categories: blindness, poor vision, mobility and dexterity, deafness, and impairment of hearing, cognition, or speech.

INDEPENDENCE AT HOME. Equipping people who are disabled and elderly with the means to be more independent also could help control health care costs. A recent study by the World Institute on Disability, a think tank in Oakland, Calif., showed that when state agencies cared for individuals with disabilities, the cost was nearly double that of independent contractors. The use of technology might further that reduction.

The possibilities are evident in a 135-year-old historic home outside Baltimore, Md. The house was recently gutted and fitted with high-tech gear by the Volunteers for Medical Engineering (VME), a group founded in 1982 by John Staehlin, an electrical engineer at Westinghouse Electric Corp.

Opened in June, the Future Home Institute demonstrates how current technology can make houses more accommodating to inhabitants, no matter what their functional limitations—and can lighten the load on their families and caretakers, said Jeffrey Jerome, director of Future Home.

Briefing a *Spectrum* visitor on a tour of the showcase house in August, Jerome showed how monitoring gear installed in all the rooms made residents feel confident that any developing emergency would be detected quickly.

In many cases, Future Home has conveniences that any upscale technophile would pounce upon, underscoring the universal design element. “There are five or six ways to control everything in this house,” boasted Jerome. Among the choices are

track balls, push buttons, remote controls with large buttons or touch screens, and voice-recognition units.

Also conducting the tour was Charles ("Dave") Ward, whose concept it was—along with VME—to build the house. Ward, who will be living there with his wife and a caretaker, has been active in designs of this kind since a fall from a tower in 1977 paralyzed him from the neck down at the age of 31.

Ward said that he plans soon to graduate to a powered wheelchair. Then, for the first time since his injury, he will be able to leave home on his own, thanks to the house's automated doors and the chin controller on the chair.

Occupants of the house control its workings through menus on TV sets in various rooms. The TV set won out over a computer as the central control unit "because it is less intimidating" and can be accessed from a distance, said Jerome. Without interrupting normal television programming, a viewer can touch a remote device to pull down the screen menus. By choosing options on the menu, the user can open power windows for ventilation, check images from infrared video cameras in bedrooms or entryways, or activate the closed captions for, say, the "Oprah" show.

Users can also call up a CD ROM from a Tandy player to read in large print what is shown on the television screen. The basic hardware and operating system for the TV interface were produced by Interior Systems Designs, Sun Valley, Calif., which does building automation work. Software was custom-written by VME.

When someone enters a room, infrared and wheelchair sensors signal doors to slide open and lights to turn on. At just the push of a button, kitchen cabinets and counters descend electrically, and temperature and water flow from the faucets are adjusted. The need to move around is minimized because many of the house's features, including the powered windows and the front door lock, can be manipulated from a chair, wheelchair, or bed.

Ward's 30 000-word Dragon Dictate system now enables him to enter about 30 words per minute. Previously, he had to hold a mouse stick between his teeth to input data to a 486 computer, and managed perhaps six to eight words a minute. "My teeth would ache at the end of the day," he said. The new unit, from Dragon Systems Inc., Newton, Mass., lists for \$695 (or \$995 for a Windows version).

The fact that the household functions are programmable means they can be matched to any combination of disabilities (mobility, visual, auditory, or cognitive). Telephone calls may be placed by voice anywhere in the house, providing residents with a sense of security, even without a full-time caregiver. Reminders for cognitively or memory-impaired individuals—

that they take a pill, for instance, or make a check-in call—can be announced over the house's intercom system.

At Future Home, demonstrations are also given of easy-to-use interfaces for a home office that will incorporate such features as home banking, shopping, and so on, as the services develop. Ward said he looked forward to the Baltimore County Library coming on-line.

For the project, low-voltage wiring—5000 meters of it—was installed, as well as US \$65 000 worth of technological equipment, including three computers, three voice-recognition units, and another 10 products containing computers. The most expensive item had a retail price of \$5000; most items were less than \$1000. The costs are relatively small compared to the \$40 000–\$50 000 yearly cost of institutional care, according to the VME.

CAUTIONARY NOTES. Even although technology has greatly improved the quality of life for the disabled, experts like Brummel warn that such developments as the rich sensory environments of multimedia communications threaten to bypass them. The protection of disabled people's right to access information is prominent in the Clinton administration's concept of the emerging National Information Infrastructure.

At its demonstration center in Washington, D.C., the U.S. General Services Administration's Clearinghouse on Computer Accommodation shows visitors model developments in information technology that assist disabled people, like appropriate multimedia kiosks. The clearinghouse's Brummel said the Government in this instance appears to be leading industry.

Other notable efforts are under way at the Trace Center at the University of Wisconsin, Madison, which is working with computer and software makers to improve accessibility to their products, as well as at Stanford University's Center for the Study of Language and Information, where researchers are working on next-generation technologies with the disabled in mind.

According to Lynn Bryant, director of Abledata, a clearinghouse of information for the disabled located in Silver Spring, Md., some 19 000 products of assistive technology are being produced by 2500 manufacturers. "In the past, assistive devices have been enormously expensive," she said, in part because they followed the health care model (where costs are dissipated among large bureaucracies). But now consumers, who are more economy minded, are comparison shopping with the help of clearinghouses like Bryant's.

In many instances, "each one of the products is the lifeblood of the person," noted Lucy Trivelli, project director at Resna, an Arlington, Va.-based interdisciplinary association for the advancement of rehabilitation and assistive technologies.

Because of the essential nature of many of

these devices, concern over product liability can scare small companies away, noted Steve Reeger, director of rehabilitation technology at the Cleveland Clinic Foundation in Ohio. And the fact that many are niche markets deters large companies. For instance, 1.2 million people use wheel chairs in the United States, and perhaps only a few hundred thousand will buy a new one each year.

To woo small companies, the National Technology Transfer Center, in Wheeling, W. Va., is designing a strategy to help them develop assistive technologies. "Most producers are small and the failure rate is very high," said Jerry Duskin, a consultant at the center who believes greater cooperation with Federal laboratories may be an answer.

As disabled persons gain influence and a greater acceptance into everyday society, technology is helping them to grow more independent. How to ensure—and enhance—that participation seems a goal well worth pursuing.

TO PROBE FURTHER. Upcoming conferences on technology and disabilities are scheduled. The IEEE Engineering in Medicine and Biology Society's annual conference in Baltimore, Md., will be held Nov. 3–6 (contact Steve Martin, Meeting Management Inc., Irvine, Calif.; 714-752-8205). On March 14–18, the 10th annual "Technology and Persons with Disabilities Conference" is to take place in Los Angeles (contact Harry Murphy, California State University, Northridge; 818-885-2578).

The American Association for the Advancement of Science, Washington, D.C., offers publications to encourage children with disabilities to pursue careers in science and engineering. Call 202-326-6440.

The Future Home Institute, which runs the new showcase home outside Baltimore, is open to the public by appointment and also provides consulting. Call 410-243-7495 or 410-455-6397.

The Abledata information clearinghouse on product information can be reached at 800-227-0216 or 301-588-9284. (Both lines provide voice and text telephone access.)

Technical journals include the Department of Veteran Affairs' quarterly *Journal of Rehabilitation Research and Development*, published in Baltimore, Md. The IEEE publishes the quarterly *Transactions on Rehabilitation Engineering*. Resna publishes the quarterly *Assistive Technology* (Arlington, Va.; 703-524-6686).

Information on the American with Disabilities Act (ADA) is available electronically from the U.S. Department of Justice's ADA bulletin board. It is accessible from the National Technical Information Service's on-line FedWorld system, reachable from the Internet (telnet fedworld.gov) or directly by modem at 703-321-8020. Also on FedWorld is a report titled *Information Infrastructure: Reaching Society's Goals*, which offers a disabilities paper by the General Services Administration for comment.

Advancing step by step

It's not easy trying to replicate control of muscles and limbs, but much progress has been made in the last 30 years

R

estoring movement to paralyzed limbs by means of electrical stimulation has been ■ research goal for over 30 years. Recently, those efforts have borne commercial fruit in ■ system that gives some people

who are paralyzed limited use of their legs. Still, before a large number of paralyzed people can achieve full dexterity and mobility, much work has yet to be done. Formidable multidisciplinary problems remain, challenging the diverse teams of engineers, physicians, and therapists who are at work on them.

According to the American Paralysis Association, Springfield, N. J., every year as many as 12 000 people in the United States alone are paralyzed because of ■ spinal injury—at an average age of 19. The U.S. population of the wholly or partly immobilized includes some 186 000 people with spinal cord injuries, about 2.5 million affected by strokes, and 1.8 million paralyzed by head injuries such as gun shot wounds.

Electrical stimulation is just one of several approaches—both short and long term—to the job of conferring mobility on injured people. Another long-term approach centers on the repair of damaged nerve tissues. Yet another is aimed at developing a robotic exoskeleton for attachment to limbs so that an arm, for example, can grasp objects. In the near term, an alternative for mobility is improvements in powered wheelchairs and more access for their users to buildings and public bathrooms.

Advances in all of these areas are worthwhile because developments in one may complement those in another. Also, some people may respond better to one form of treatment than to another.

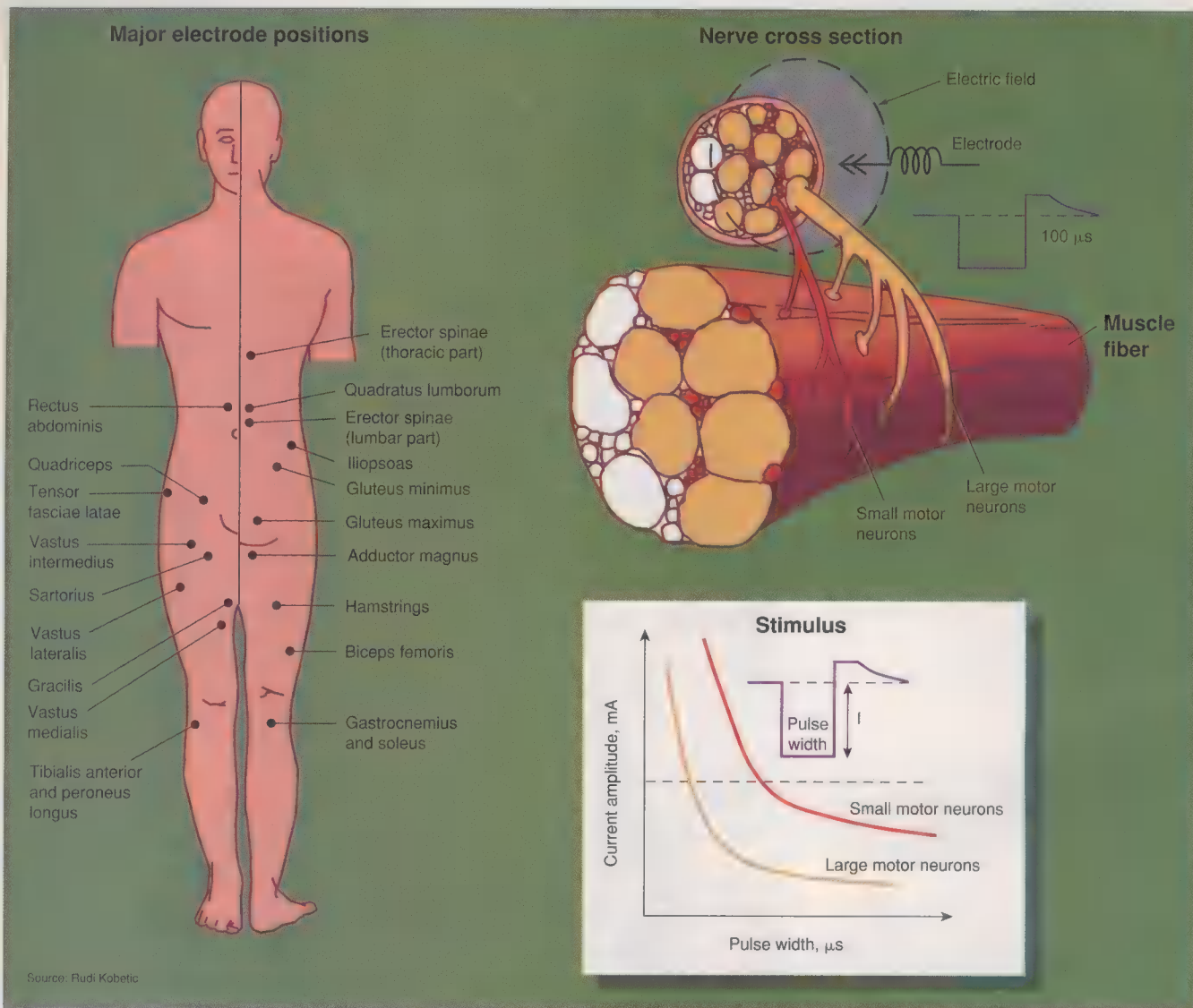
The new U.S.-approved commercial system is one in a group known as functional

Rudi Kobetic Cleveland Veterans Affairs Medical Center



[1] At the Cleveland Veterans Affairs Medical Center, in Ohio, 13 people are using an experimental system that enables them to walk for short periods, climb stairs, and step sideways. The system stimulates their neuromusculature electrically through up to 48 electrodes.

Cleveland Veterans Affairs Medical Center



[2] The key areas for implanting electrodes to stimulate walking extend from the chest to below the knee [left]. As an electrode enters the muscle, it is anchored near a nerve branch that contains many neurons specific to that muscle. Each motor neuron triggers from three to 200 muscle fibers.

Because the threshold for stimulus is lower on large motor neurons, an electric field recruits them more easily than it does the smaller neurons. More powerful "fast-twitch" fibers are thus activated more readily than "slow twitch" small fibers, which, however, have greater endurance. Varying pulse width will recruit different muscle fibers. When stimulation issues pulse widths of 150 ms, more fibers of all types are recruited. In contrast, with natural control from the brain's cortex, only small fatigue-resistant fibers are active when small forces are required; large fibers are recruited only when strong forces are needed.

electrical stimulation (FES) systems. Basically, a computer coordinates sequences of electrical pulses through a network of electrodes attached to the body. This causes the appropriate muscles to contract and effect movement and control.

Important FES work is taking place in Australia, Austria, Canada, France, Japan, the Netherlands, Slovenia, and the United States. Most development is being done in research laboratories, but several companies, like Tokyo's NEC Corp. and Medtronic Inc., Minneapolis, Minn., are also involved.

Besides helping people walk, FES is being examined as a medical aid for the heart, for breathing and coughing, and for bladder and rectum control. It is also being applied to stimulate muscles in the arm and shoulder,

and in the hand, for grasping and releasing objects. Thanks to advances in miniaturization and surgical techniques, FES systems have also been implanted in the upper body to permit arm movements.

But applying FES to walking is probably the most complex work being carried out. This is because of the strains involved in the leg muscles and the urgency of maintaining balance during each 2-second-long average walk cycle.

To date, experimental systems in clinical laboratories have helped many paralyzed patients to stand up and walk for a short time, and some to even climb stairs. Such limited capability can be useful in such everyday tasks as reaching for objects, turning on a light switch, or overcoming obstacles in a

friend's home or a restaurant. But extended walking and maneuverability remains ■ distant goal.

STIMULATING STORY. In the early 19th century, Duchenne de Boulogne devised electrodes for stimulation through the skin by using an alternating current, a technique still widely employed in physical therapy today for the rehabilitation of muscles. (Nerves do not respond to direct current but rather to the oscillations of ac.)

De Boulogne also observed that stimulation at certain locations on the body produced better muscle contractions. Known as motor points, these sites were later found to correspond to points where nerves enter the musculature.

In the 1960s, ■ number of patents were

issued for electrical stimulation systems to aid ambulation in people with paralysis (one of the most notable went to Wladimir T. Liberson). During the same period, a group of engineers and physicians at Case Western Reserve University in Cleveland, Ohio, began using FES to attempt to restore hand grasp to quadriplegic patients.

The need to activate select muscles only prompted the development of a coiled-wire electrode. This advance meant power could be applied below the surface of the skin with electrodes implanted directly at or near the motor points, activating specific muscles and using smaller electric fields. The coils were for springiness, to reduce stresses on the electrode due to muscle flexing.

The following decade, extensive work was carried out on the application of surface electrical stimulation to paraplegic patients, to help them stand and take steps. The most notable of these efforts was made by Alojz Kralj and his colleagues in Slovenia.

In the mid-1980s, the FES field achieved some notoriety, culminating in an episode on "60 Minutes," the U.S. television program. The show focused on FES work being done at Wright State University in Dayton, Ohio, where researchers were claiming that a closed-loop system with enhanced control would enable paraplegic people to walk with real-time feedback. Those claims later proved to be unfounded.

Today research on FES continues on many fronts in hopes of improving its commercial offerings. A recent development was the Parastep surface stimulation system by Sigmedics Inc., Northville, Ill., approved this year by the U.S. Food and Drug Administration for use in the United States. Another was a 16-electrode implantable-electrode stimulation system manufactured by NEC Corp., Tokyo, based on the work of Y. Handa and his colleagues at the Tohoku University School of Medicine, Sendai, Japan.

Stimulation systems that get people walking cost about US \$15 000 and are usually combined with extensive bracing support. The stimulation furnishes the power for moving the body forward and the bracing supplies the stability. In addition, the brace allows a person to stop and rest, using as little energy as when sitting down. This may well be the best intermediate solution, for researchers still have much to learn about controlling this bio-electronic system, with its multiple degrees of freedom and nonlinear, time-dependent variables.

WALKING WISDOM. Though most people take it for granted, standing upright is a complex task to mimic artificially—and walking is even more so. Leading FES researchers in Sendai, Japan, reported on the state of artificially induced standing at the 1993 annual conference of the IEEE Engineering in Medicine and Biology Society. In their research, they found that two healthy paraplegic persons in their twenties, supporting 100 percent of their body weight without braces, could stand for 30

minutes with the help of FES. The charges were distributed by as many as 30 percutaneous (that is, through the skin) electrodes.

Even so, the patients had to put one hand on a wheelchair or parallel bar to balance themselves. Providing the ability to stand alone will not be possible, the researchers concluded, until real-time feedback control with a greater degree of sophistication—the coveted closed-loop system—is made practical.

What makes walking even harder to artificially mimic is the perfection achieved over the long course of evolution. The failure to simulate that perfection after just 30 years of laboratory work is hardly surprising.

People with functional neuromuscular systems can walk briskly for long distances without getting tired. Endurance is built up because during natural movement the brain places priority on using slow-twitch muscle fibers of an aerobic metabolism (high oxidative enzyme activity). The pathways to these fibers are through the small motor neurons. When special exertion is needed, fast-twitch muscle fibers with an anaerobic metabolism (high glycolytic enzyme activity) are called into action by larger neurons.

In contrast, FES helps handicapped people walk by recruiting motor neurons in reverse, energizing those in the fast-twitch muscle fibers first [Fig. 2]. The larger nerve fibers have a lower threshold to electrical stimulation. (The excitation threshold is inversely related to fiber diameter.) Although the fast-twitch glycolytic fibers have greater strength than slow-twitch fibers, they fatigue more easily. The result is that artificially stimulated muscles tire faster when performing a repetitive task.

The force available to the muscle is also reduced. Eventually, chronic electrical stimulation can transform fast-twitch fibers into slow-twitch, fatigue-resistant fibers. But these muscle fibers produce less force per unit area, so normal forces cannot be attained. While an able-bodied person may expend only one-third of his energy on walking, a disabled person in an FES gait will be using his muscle system to the full.

Another shortcoming of FES is the interface that applies the electricity. A muscle may have thousands of motor units, each combining one axon and 3–200 muscle fibers. At its present level of interfacing, FES cannot fire the axons to stimulate the muscles in a natural, asynchronous way. Electrodes interface with nerve trunks, not axons, and artificial stimulation gives a synchronous jolt to all the axons.

GET UP AND GO. At the Veterans Affairs Medical Center in Cleveland, Ohio, over a dozen people regularly use FES walking systems, having first had electrodes implanted in their bodies. They all require the

A sampling of the menu for functional electrical stimulation

Main menu	Joystick pad options
Stand	Walk, Right sidestep, Step back, Upstairs, Downstairs, Sit, Left leg first (walk), Left leg first (ascend)
Exercise	Foot tap, Leg kick, Knee bend, Arch back, Lean right, Spread knees, Pelvic thrust
Set-up	Set maximum pulse widths, tune joystick, set thresholds for force-sensing resistors, set compliance monitor for standing, walking, and exercise records

support of a walker. The system has FDA approval for clinical tests on 50 subjects.

The key to these systems is an array of up to 48 stainless-steel electrodes. These are surgically implanted in a person's legs and trunk and then brought out to eight connectors (four on each side of the body). Not all the subjects need the full 48-electrode array—8 to 16 are enough for those paralyzed by a stroke down one side and those who are partially quadriplegic (who stand and thereby use only knee, hip, and trunk extensor muscles).

A person generally needs less than 5 minutes to equip himself to walk. Around his waist he straps on a belt that contains batteries and a microprocessor-controlled stimulator. Two ribbon cables from the stimulator attach to the eight connectors on which the implanted electrodes terminate. The only bracing worn is an ankle-foot orthosis, to prevent sprains. The orthosis may also be instrumented to let the controller know when a heel has touched down.

To start moving, the subject uses a tiny joystick and pad, which fits like a ring onto his hand. He can choose to move forward step by step or faster in an automatic mode. Turns are made by moving a walker, which the subject usually leans on with both hands to stabilize himself. Average walking distances are measured in tens of meters. No system anywhere can yet offer long walks in the park.

By changing modes with the joystick pad, the subject can also do exercises, step backward, or step left or right [see table, above]. The latter features are useful for sitting in a chair or, leaving the walker aside, for moving into a row of seats in a theater or ballpark. They can be helpful, too, in moving about in small bathrooms. The number of electrodes and the limited bracing in this system leave the joints free to move so that the person can climb or descend a flight of stairs.

Besides increasing mobility and independence, FES has some health benefits. Since it enables a disabled person to stand or walk, the joints are taken through a range of motions, preventing muscle from

shortening and joints from becoming fixed in a flexed position. Osteoporosis is therefore reduced. Of course, there are also benefits from the aerobic exercise.

BETTER ELECTRODES. Of the many areas of FES work that need improvement, the electrode is one of the most important. Though

many modifications have been made in the coiled-wire electrode since it was first implanted in the early 1960s, it still copes poorly with leg muscles because of their tremendous shear and tensile stresses.

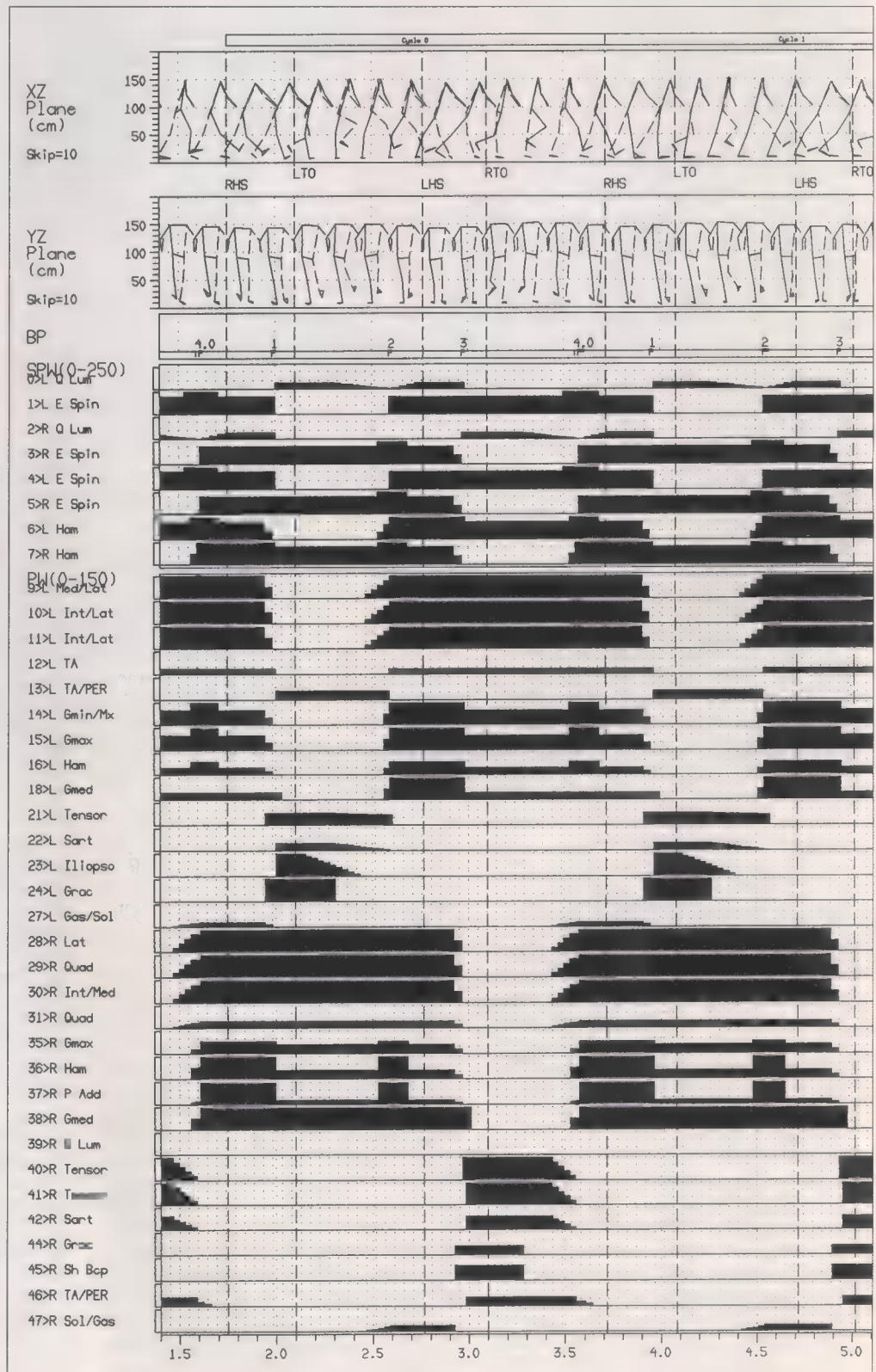
Today's coiled-wire electrode, with an outside diameter of 0.56 mm, is made from

multistrand stainless steel and coated with Teflon. Tiny barbs anchor it near the nerve trunk, which measures about 1-3 mm across. The lead is tunneled under the skin to a common exit site where it is soldered to a small connector. Ribbon cables attached to these connectors access the

[3] Artificial walking is triggered by a coordinated, periodic firing of nerves and muscles. During the 2 seconds of a walk cycle, more than a dozen muscles from the trunk to the calves are stimulated. There are two modes for walking forward: one that uses a weaker stimulus to start with, and the other, shown here, that uses longer pulse widths to recruit more muscle fibers. [Progress is shown in the stick figures at top, with muscle electrode channels at left. The dark patterns show variations in pulse widths over time.]

As the right heel contacts the ground (at 1.75 seconds), knee, hip, and trunk extensors are activated. (The first prevent collapse, the second renew forward momentum, and the third help keep the body erect.) At about 2 seconds, the left leg prepares to swing by activating left hip flexors 21, 22, 23, and 24.

Around 2.9 seconds, the right stance is completed as channels 28-38 are turned off and the leg prepares to swing, activating channels in the 40s. Many of the muscles are at peak stimulation, with pulse widths of 150 ms. When possible, the pulse widths are shorter, to reduce fatigue. The sequencing patterns are preprogrammed and vary for each patient. (This one had many muscles in need of heavy stimulation.)



stimulator when a person dons his belt for walking.

The survival rate of this electrode is 70 percent at one year and 62 percent at five years. Most failures are attributed either to the movement of the electrode away from the nerve or to the fracture of the lead. For a practical system for walking, a tougher electrode is needed, so that no more than one replacement is required per system per year.

Also needing improvement is installation of the coiled-wire electrode. It is now blindly implanted near a motor point by means of a hypodermic needle. Efforts are under way to develop endoscopic tools and techniques for installing these implants with greater accuracy and less trauma to the patient at the same time. The latter consideration is particularly critical when over 40 electrodes need to be implanted.

Additional devices are in the works. One innovation being considered is suturing a disk-shaped electrode directly onto the muscle at the point of nerve entry. Called an epimysial electrode, this device has been used to activate muscles involved in grasping in someone who is quadriplegic.

Another type, the nerve cuff electrode, is placed around the nerve. Medtronic Inc. demonstrated a nerve cuff electrode in a foot-drop correction system for people who have had a stroke; it was evaluated by the Rancho Los Amigos Hospital in Los Angeles.

While both these electrode types appear to be more reliable than simple coiled-wire units, they do have a down side: both require extensive surgery, which is undesirable to a lot of people, especially when their application needs many electrodes.

STIMULATION CONTROL. The task of activating and controlling muscle movement falls to the stimulator. In the Cleveland system, a 16-bit microprocessor controls the stimulation, which is a coordinated burst of electrical pulses of a certain duration. The sequences of pulses vary, of course, depending on the desired movement. Within repeated movements, pulse widths are often varied for a given muscle to recruit different fibers.

For stimulation beneath the skin in intramuscular electrodes, the amplitude is kept at 20 mA and the pulse width is modulated between zero and 150 ms. If surface stimulation is used for, say, an area with no implanted electrodes, pulses of 100 mA are used. A digital input signal is transformed into a biphasic, balanced-charge waveform.

Feedback comes from up to eight channels of force-sensing resistors for measuring foot contact pressure. Other channels are available for accelerometers, for goniometer sensors to measure joint angles, or for other sensors that may also help in closed-loop control of the stimulation.

With advances in multichip module electronics packaging, stimulators may be reduced to pager size. Not just electrodes, but whole systems, including stimulators, may be implanted for some applications.

The Cleveland FES Center, in cooperation with Case Western Reserve University, has implanted eight-channel stimulators to control hand grasping in people who are quadriplegic. For upper extremities use, clinical trials are proceeding in Australia, Canada, and the United States. To activate the correct electrode, a circuit is interfaced to an external bus that encodes an RF signal of the transmitter with both pulse width and channel select information. Power for the stimulation is also transmitted.

PROGRAMMING MUSCLES. Walking is part of a person's signature—highly individualistic. Not surprisingly, each person using an FES walking system requires different programming, and programming needs alter over time. It is now a rather imprecise art that relies mainly on preprogramming and trial-and-error tactics using general motion analysis models. Nor is there much real-time individual feedback, other than pressure sensors on feet.

With as many as 48 electrodes in the Cleveland walking system, researchers can program all major muscles related to walking, from the trunk to the ankle. This produces a smoother gait and permits such functions as sidestepping. A typical two-step walking cycle for nondisabled people is 1.5 seconds; for these Cleveland subjects, it is about 2 seconds [Fig. 3].

Either amplitude or pulse-width modulation may be used to control muscle activation by regulating the number of muscle fibers recruited to produce muscle force. In Cleveland, trains of pulse widths of up to 150 ms are varied for control, at repetition rates of 15–50 Hz. Higher pulse repetition rates result in quick muscle fatigue and no notable increment in force. At rates much below 15 Hz, the muscle contraction is not fused: the bunch of fibers may tremble but not reach the point of tetanic activation.

A series of pulses—often at the peak of 150 ms for each muscle—is needed to provoke movement of the limb. Response times vary, but it typically takes 100–300 ms to raise or relax a limb. The variation depends on the mix of slow- and fast-twitch muscle fibers that are recruited. Conditioned FES muscles are composed mainly of slow-twitch fibers that respond slowly when stimulated.

The response time is also influenced by the interval between the pulses and by muscle fatigue. The sequences of pulses to each muscle are delivered in a preprogrammed stimulation pattern based on well-known normal electromyographic activity. It is modified by trial-and-error solutions for each patient.

During training, the subject learns to incorporate FES-driven motions in his or her activities. Tuning of stimulation patterns is essential until a stable state is arrived at—that is, once all the electrodes have been implanted and the muscles are well conditioned. While rough tuning may

be based on visual observations, fine tuning calls for quantitative evaluation with a motion analysis system. The better tuned the FES system is, the less energy is used.

When motion and analysis data are combined with ground reaction forces, as measured by force plates located in a walkway, there is enough information to determine both the positions of body segments in three-dimensional space and the joint moments generating the movements. As a result, changes can be made in stimulation patterns to create a more natural-looking gait. The stimulation patterns are generated on a Micro Vax II computer and downloaded into the subject's stimulator.

FUZZY FUTURE? An elusive goal is responsive closed-loop systems that adjust in real time to the changing state of the subject's muscles and joint angles. As the Sendai, Japan, researchers determined in their report last year, a closed-loop system would be required to give a person more stability and the ability to stand erect with both hands free. In an application like standing, many muscles might have to be stimulated full blast, full time, because of the absence of information on selective force needs.

But closed-loop systems require information from sensors mounted on the skin or from braces that would modulate stimulation in real time to produce the desired results. While feasible perhaps for standing or upper extremity control, this information may be too difficult to achieve for walking, a feat that combines nonlinear properties of muscle with time dependency.

Fuzzy logic control appears to be a much more promising approach, and is being pursued at the Cleveland Center. Corrections, based on experience gained by experts with preprogrammed stimulation, are made not in real time but at each succeeding step. Adjustments are made by measuring the deviation from parameters such as knee angle, with adjustments continuing until the deviation is brought to zero.

A long-term goal for FES researchers is unobtrusive implantable systems that could automatically adjust the stimulations. The result would be a less cumbersome apparatus that would provide near-normal functions to people with paraplegia, most likely with the support of crutches or a cane.

TO PROBE FURTHER. Excellent reviews are *Functional Electrical Stimulation: Standing and Walking after Spinal Cord Injury*, by Alojz Kralj and Tadej Bajd (CRC Press Inc., Boca Raton, Fla., 1989), and *Human Walking*, edited by Jessica Rose and James Gamble (Williams & Wilkins, Baltimore, Md., 1994). ♦

ABOUT THE AUTHOR. Rudi Kobetic is a supervisory biomedical engineer at the Motion Study Laboratory at the Veterans Affairs Medical Center, Cleveland, Ohio. Since 1980 he has been the co-principal investigator (with E.B. Masola) on the project developing functional electrical stimulation systems for walking in paraplegia.

Appropriate technologies

The use of technology to improve the health and general well-being of much of the world's population—and do so at affordable cost—presents electrical and electronics engineers with unusual challenges and opportunities

The ending of the Cold War has released more energy for tackling the concerns of underprivileged populations. "One billion people in the developing world still lack access to clean water... nearly 2 billion lack adequate sanitation...Electric power has yet to reach 2 billion people," the World Bank noted in its June *World development report 1994: infrastructure for development*.

A country's infrastructure includes services based on electrotechnology, such as electric power, telecommunications, and road, sea, and air transport. Developing countries in round figures pour US \$200 000 million every year into new infrastructure, amounting to 4 percent of their national output and a fifth of their total investment, according to the World Bank report.

In purely human terms, the situation of these people is unacceptable. Technologically, it dares electrical and electronics engineers to devise remedies by applying proven technology at an affordable cost.

One challenge may well be to upgrade the infrastructure in developing countries. At present, for example, about 40 percent of their power-generating capacity is on average unavailable when needed, as a result of malfunction or scheduled maintenance; elsewhere, in the best-performing power sectors in the world, the percentage is half that figure, according to the 1994 World Bank report.

To cut back on waste and improve efficiency, the bank is embarking on a thorough reform. Among its goals are to see the infrastructure managed as a business, and not as a bureaucracy; to see competition introduced; and to give those who use the services a stronger voice in and responsibility for their operation than has been the custom.

But what exactly is a developing country? The World Bank often refers to "de-

veloping economies" as those with low or middle per-capita income, derived by dividing the gross national product (GNP) by the population count.

Low-income countries, with US \$675 or less per capita, include Burundi and Benin in sub-Saharan Africa, Egypt in North Africa, Cambodia in East Asia, Tadjikistan in Central Asia, and Haiti in the Americas. Senegal, though, and Thailand, Turkey, Iran, Algeria, and Chile are representative of middle-income economies, with \$675–\$8356 per capita income (in 1992). (All dollar figures are for U.S. currency.)

In this issue, *IEEE Spectrum* is launching a series of articles on technology appropriate for developing countries. Topics will include photovoltaics applications, telecommunications, computers and networks, and electrotechnology applications in such areas as transportation and agriculture. Intuitive, qualitative criteria for appropriateness have been adopted for the series. An appropriate technology is one that:

- Fits in the country's infrastructure.
- Is affordable.
- Can be properly maintained.
- Is not destructive to the environment.

The requirements need not imply technological inferiority. Indeed, a developing country quite often seeks to leapfrog straight into the 21st century, particularly if the leap makes sound economic sense. Indonesia is doing just that. Looking to a rapid expansion of its urban telephone network, it is installing a radio-based, cellular-telephone system in Jakarta and West Java for a total of 280 000 subscribers.

The first topic covered in the appropriate technology series is photovoltaics, which has the potential of bringing electric energy to millions of remote rural households, greatly enhancing their quality of life.

So rosy, in fact, is its promise that the 12th European Photovoltaics Solar Energy Conference and Exhibition devoted a parallel symposium to photovoltaics in developing countries. Inspired in part by that symposium, which was held in April in Amster-

dam, the Netherlands, the following report includes an overview of the technology's applications and two regional studies, one on a large project in West Africa, and the other about India.

Photovoltaics is attractive because it can help countries avoid the huge expense of expanding electric grids into rural areas, at an estimated cost of \$20 000–\$30 000 per kilometer, reports Erik H. Lysen, the head of a department at Novem, the Netherlands agency for energy and the environment located in Utrecht. But if affordable power is to be supplied by this means to millions of rural households, the worldwide manufacturing capacity for photovoltaic modules and systems will have to be substantially enlarged, he noted. Furthermore, funding for photovoltaics applications by national and international organizations would have to be increased by orders of magnitude, he said [pp. 34–39].

International cooperation counts heavily toward the success of photovoltaics applications. Evidence of that comes from projects in Vietnam and the republic of Kiribati in the mid-Pacific [p. 39].

In West Africa, high grades are scored by a program for installing photovoltaic systems with 1200 peak kilowatt capacity for water pumping, refrigeration, and lighting [pp. 40–43]. And in India, about 62 000 rural photovoltaic systems have already been installed under a government-assisted program, and the installation of 60 000 units that power VHF remote radio links is under way [pp. 44–46].

From these and other reports it is clear that designing "appropriate" technology may sound easier than it is. In the West Africa project, for instance, inverters for water pumps had to be flexible enough to accommodate various pump capacities, pipe sizes, and water heads, but this flexibility could not be bought by sacrificing efficiency. Protection of the photovoltaic system against lightning and the safety of maintenance personnel also came into the picture in a big way.

Even so, the obstacles that photovoltaics must overcome are more institutional in nature than technological, as became very clear at the Amsterdam meeting. More than 30 years in the making, photovoltaics is mature enough in itself, but will require innovative breakthroughs in financing as well as changes in energy policy, the experts believe.

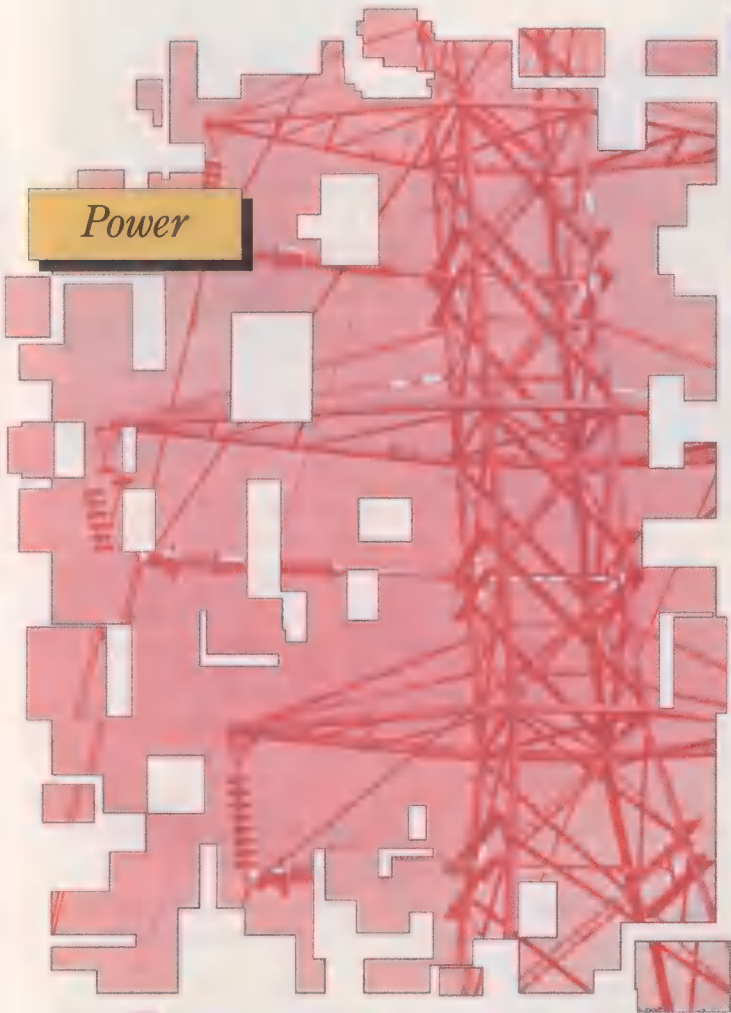
Gadi Kaplan

Senior Technical Editor

Telecommunications



Power



Transportation



Materials



Photos (satellite dish, truck): Superstock, Inc.
Image manipulation: Armand Veneziano

Technologies appropriate to developing countries are contributing vital pieces to those economies' incomplete infrastructures. The approach takes into account the environment and incomes. Power, telecommunications, transportation, and materials are among the fields involved.

Photovolts for villages

Innovative financing schemes enable households in remote areas to buy domestic solar systems that run for \$5 or less a month

Two billion people are without an electrical connection, but the cost of hooking up their homes to a conventional grid system will be too high for most developing countries. Photovoltaic solar systems are a cheaper alternative and can reach virtually any site on earth. Granted, new and bold initiatives are necessary to realize the required 20 000-MW peak power of photovoltaic capacity. But the breakthroughs needed are less technical and more in the areas of financing and energy policy.

Energy is not the most pressing problem of the developing countries, partly because oil prices are at present so low. Instead, they have to worry about the poverty of most of the inhabitants, their food supply, the creation of sufficient and meaningful jobs, competition in international markets for their products, and, sadly enough in some cases, the presence of war. The main energy problem in rural areas still is to find enough wood for cooking meals. In some developing countries, biomass for cooking accounts for over half of the national energy consumption.

For some decades now, photovoltaics (PV) has been on the energy scene in the developing world, particularly in established niche markets such as telecommunications, marine beacons, railway signaling, and cathodic protection of pipelines. The challenge will be to apply PV to the provision of energy to rural homes for lighting, refrigeration, and TV.

The most successful to date is the individually owned solar home system: typically a 50-W solar panel that charges a battery by day and powers loads after dark. Owners are proud of having their own power system and are not susceptible to grid failure or inconsiderate neighbors, while the equipment itself can be expanded

when required. Of course, the systems must be well designed, properly maintained, and paid for by the owner, because giveaways seldom last long.

On the face of it, it looks strange that people in rural areas and nonindustrialized countries are satisfied with a fraction of a kilowatt-hour a day, whereas residents of industrialized countries "need" 10 kWh or more per day. The explanation is that people are not interested in kilowatt-hours as such, but in light, a working TV set, or a refrigerator. In other words, they want the services of the energy regardless of whether it amounts to 0.1 kWh or 10 kWh per day. And as only a limited number of solar kilowatt-hours are available, people cannot afford to waste them and must use efficient lighting, low-power TV sets (a golden market for future flat-screen TV sets with liquid-crystal displays), and efficient refrigerators.

The only thing that matters to the owner is: how much do I have to pay for these services every week or month? As a first estimate, a reasonable part of the rural population can raise \$5 to \$8 per month. This is what they are paying now for kerosene lighting and for battery charging at grid-connected centers. (All dollar figures in this article refer to U.S. currency.)

As is well known, nearly all utilities in developing countries are losing money on rural electrification. Investment capital is not the problem, being available at comparatively low rates from large multilateral banks like the World Bank and Asian Development Bank. High costs are the issue, stemming from long transmission lines to remote customers, low consumption, the need to charge only low tariffs, and high technical and nontechnical losses (transmission and distribution losses and illegal connections)—20–40 percent in some countries. And these high costs are usually cross-subsidized by urban consumers.

Line costs are the heaviest burden, usually accounting for 80–90 percent of the budget of a rural electrification project. They typically run \$20 000–\$30 000 per kilometer. Another factor is the widely variable number of users per kilometer of line, which may be as low as two but in Bangladesh must be at least 75. As a result, the average cost per rural connection also varies wildly: Mohan Munasinghe, an energy expert with the World Bank,

quotes a range from \$200 to \$3650 (in 1983 prices). The monthly power consumption of rural consumers is usually low: 20–40 kWh, leading to high per-kilowatt-hour costs of 10–20 cents to \$1.

POWER TO THE PEOPLE. A recent report from the World Bank on its role in the power sector notes that the number of power connections in developing countries in the period 1969–89 grew by 9 percent per year, or 2.5 times the average population growth. In spite of this rapid growth, rather few members of the population are yet connected to an electricity supply. Average real power tariffs declined from 5.2 to 3.8 cents per kilowatt-hour in the period 1979–88 (in 1986 dollars).

Nevertheless, governments and utilities in developing countries have impressive plans for expanding their power sectors. The idea is to increase the total power supply capacity from the 471 GW of 1989 to 855 GW in 1999. It is estimated that no less than \$1 trillion will be needed to achieve the desired 384-GW increase. Approximately 40 percent of this sum is in foreign exchange, and it is clear that the \$40 billion needed annually cannot be mobilized, even by the large multilateral banks (the present level of World Bank lending for the power sector is around \$7 billion per year).

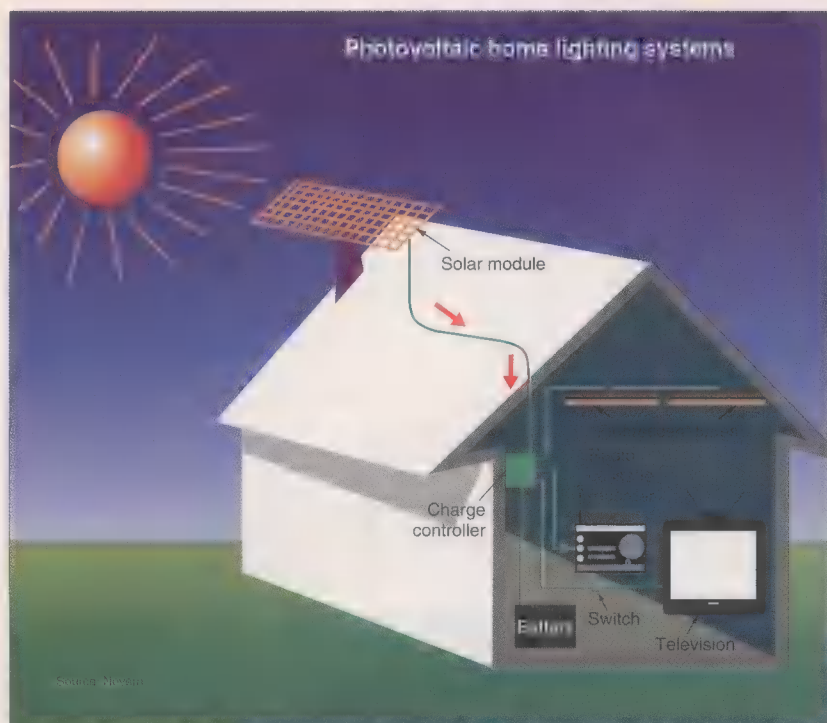
The conclusion seems inescapable. Governments in the developing world will face great difficulties in expanding their power sectors as planned. Obviously, too, priority will be given to industry and the urban sector. This prospect underlines the need to consider other alternatives for rural electrification, such as pre-electrification through PV or other renewable sources.

THE STORY TILL NOW. One of the earliest references to photovoltaics in a rural setting is to a system installed in Chile in 1960. In the '60s, PV cell development was dominated by research for space applications (the first satellite was launched in 1957).

Rural energy developments in the '70s were typically the so-called "integrated energy systems" promoted by the United Nations. These projects characteristically exploited various sources of renewable energy (such as the sun and wind, biomass, and organic waste), and they distributed the electricity thus obtained through a regular grid system in the village. In practice these systems never came up to expectation; they

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A typical photovoltaic (PV) solar home system includes a photovoltaic panel that charges a battery through a controller. The battery powers lights, and television and radio sets.

A 50-W photovoltaic panel atop a house in Pansiyagama, Sri Lanka, supplies power for light and a television set to its residents [top, right].

A family in Indonesia watches a program on a PV-powered television set [middle].

A street light and a rural house are powered by a photovoltaic system in Sukatani, Java, the first photovoltaic project undertaken in Indonesia.



demanded too much maintenance, were poorly designed, gave unreliable service and, most importantly, were more or less forced upon the village inhabitants.

Individual solar home systems were introduced more or less independently in the Philippines, the Dominican Republic, and Indonesia in the early 1980s.

The Philippine-German Solar Energy project (1982–88) started with a 13-kW plant for a small village. The plant was found to be not economical for wide dissemination. The second phase emphasized small PV systems for use in rural areas, namely, solar home systems and communal battery-charging stations. The first 100 of these home systems were installed at Burias Island. A would-be owner had to make a down payment of \$140 and 36 monthly payments of \$13.

An important lesson was learned. Solar home systems have become a status symbol, because they are one of the few high-tech systems available outside urban areas and they open the door to radio, TV, and video. At present, about 105 kW of solar systems are installed in the Philippines, of which 70 kW is in residential systems and 35 kW is in systems intended for telecommunications,

pumping, and other purposes.

In the Dominican Republic, a true catalyst for the development of photovoltaics was the presence of Richard Hansen, founder of Enersol Associates (USA). In April 1984 the first PV system was installed in Bella Vista. Right from the beginning, owners had to pay for the system (48 monthly installments of \$10). Soon a solar credit fund was created (Adesol) with seed money from the U.S. Agency for International Development, and from the installments paid by its clients new systems could soon be bought. Local entrepreneurs were trained for servicing and sales of new systems.

By mid-1987 more than a hundred systems were up and running. That year, the Solar-Based Rural Electrification Concept was introduced, as a model for intervention by a nongovernmental organization, and gradually spread. By 1992 the number of PV systems grew to 4000. More than 10 installation businesses are active in the Dominican Republic.

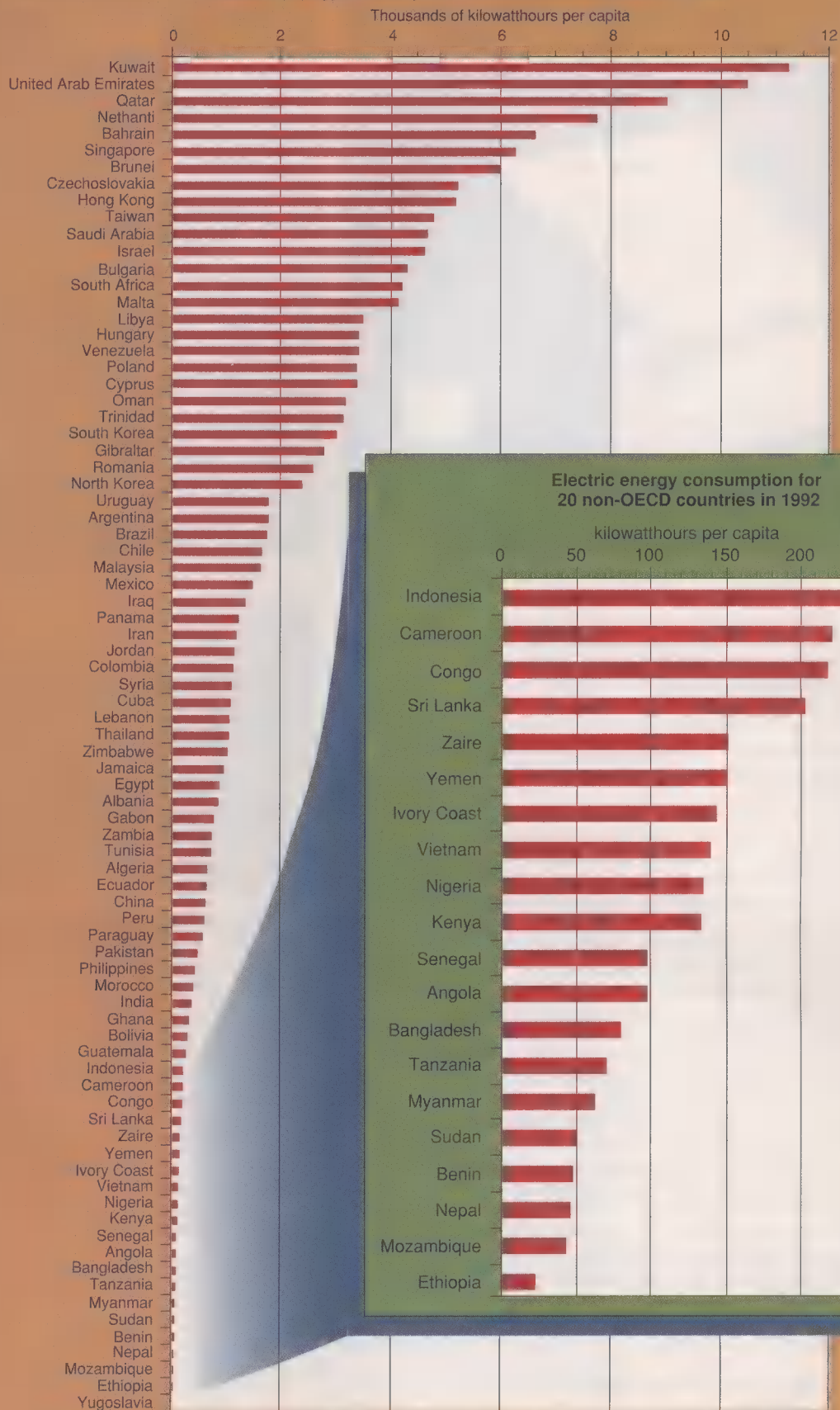
The development of solar home systems in Indonesia was the fruit of cooperation between individuals and the Dutch PV company R&S (Renewable Energy

Systems), the Indonesian Ministry of Research and Technology, and the Indonesian Ministry for Cooperatives. A start was made in 1987 and in 1988 the systems were demonstrated in Sukatani, a village 110 km from Jakarta. The seed money was provided by the three organizations listed above plus the Netherlands Ministry of Foreign Affairs.

Sukatani has a lower than average amount of sunshine. The idea was that if the system worked there (which it did), it would work throughout Indonesia. The local cooperative took responsibility for fee collection and simple maintenance.

The President of Indonesia became so enthusiastic about the Sukatani project that he started the Banpres project, with interest-free credit for 3000 solar home systems, which have since been successfully installed. Additional credit schemes through revolving funds have been started, one example being the \$50 000 revolving fund grant from the North Holland utility PEN, for solar home systems in the village of Lebak.

Electric energy consumption for non-OECD countries in 1992



Source: Organization for Economic Cooperation and Development (OECD).

By 1993 more than 10 000 home systems had been installed throughout Indonesia. The average investment has dropped below \$400, and with a down payment of 35 percent the solar home system owner pays the equivalent of \$8 per month.

FIVE TYPES OF PROBLEMS. As with every new technology, all was not smooth sailing. Problems that arose during the systems' introduction fall into the following five categories: financial, institutional, interpersonal, infrastructural, and technical.

Financing the purchase is still the most forbidding hurdle. The average price of a solar home system is about \$500. But in many countries, only 10–20 percent of rural families earn more than \$100 per month. Assuming that 10 percent can be spent on a solar home system, this means they can afford a maximum of \$10 per month, and preferably less. The problem therefore is how to reduce the monthly installments to, say, \$5 per month.

Institutional conflicts are the next concern. Electric utilities are traditionally either hostile or at best indifferent to small autonomous systems such as solar systems for the home. It can happen that a non-governmental organization pushes hard to install solar home systems in a village, only for the utility to show up with a grid extension a few months later. Confusion is created and part of the investment in home systems suffers. Rural electrification policies seldom include pre-electrification options such as solar home systems, or wind or microhydro supply systems.

Experience has shown that interpersonal relations were often mishandled. People were not properly involved in a timely fashion in the decision to introduce PV systems. They were not informed about the performance of the solar home system and its pluses and minuses compared to a grid connection. Training of the owners was sometimes inadequate, so that batteries were discharged too deeply if poor (or no) controllers were present. Simple but essential repairs took much too long, so that people lost confidence in the system. The key factor here is proper communication with the users.

This situation is closely linked to infrastructural weakness. Often after-sales service was either nonexistent or poorly organized. Publicity was insufficient, wrongly targeted, or even negative. Stories about failures tend to stick in people's minds for a long time, and 10 times as many successes are needed to eradicate them.

Then of course there were the technical problems associated with a new technology. Interestingly, there were hardly any problems with the PV modules. The trouble came from conventional parts of the system—batteries, controllers, and lights and switches. Controllers worked poorly or were omitted to save money, so batteries had a short life. Cheap fluorescent light tubes were used, which blackened quickly; electronic ballasts failed and switches malfunctioned.

In essence, the financing problem can be solved by lowering the investment cost of

the PV system and by enabling the customers to pay smaller amounts over longer periods. The first part of the solution is largely for the manufacturers to implement and is influenced by Western development programs. The developing countries' governments can help by lowering or waiving import duties.

Several options for lowering the monthly costs for consumers have been proposed and are being practiced: revolving funds (started with grants); presidential loans (as in Indonesia); local bank loans; the Finesse approach (financing of energy services for small-scale energy consumers); and supplier's credit.

Energy experts made a good point during the Finesse workshop held in October 1991 in Kuala Lumpur with the support of the World Bank, the U.S. Department of Energy (DOE), and the Netherlands Ministry of Foreign Affairs. Given that large power companies have access to very cheap capital for new power plants and rural electrification projects, they argued, smaller-scale power options that complement the grid supply should also be allowed to tap just a fraction of those funds, and on the same conditions. Solar home systems were seen as a case in point.

This is in essence the aim of the Asia Technical Alternative Energy unit of the World Bank, which is supported by (among others) the DOE and the Netherlands Ministry of Foreign Affairs. The unit at present is active in Indonesia, India, Sri Lanka, and China.

On the institutional level, clashes with the electricity companies can be avoided if the initiatives in solar home systems are coordinated or even channeled through them. The utilities should permit, spur on, or even contract with the private sector and nongovernment organizations to start offering solar home systems in certain areas. They should make it clear to the customers that this is a pre-electrification option, and that if in the future the utilities have the means to reach the village by the grid, the PV panels can be resold to the private sector (or kept as an emergency option).

Events in the Philippines, Dominican Republic, and Indonesia prove that the early involvement of potential customers is crucial to the success of any PV project. People should be properly taught about system operation and properly informed about comparative performance and costs. A warning system for larger breakdowns should be set up, to ensure quick repairs and maintain confidence in the system. Local cooperatives should be used to collect fees and carry out basic maintenance. Local youths should be trained as PV technicians and paid for their work.

Improvements in product quality have occurred over the last few years, thanks

Worldly wealth in watt-hours

One measure of a country's economic well-being is how much electrical energy its people consume per capita. These data are compiled in Paris by the International Energy Agency of the Organization for Economic Cooperation and Development (OECD). The agency's figures reveal that Norway tops the list—it consumed 23 000 kWh per capita in 1992 [see illustration]. Ethiopia, at the other end of the scale (though, of course, with a much warmer climate) used a mere 23 kWh per capita, or 0.1 percent of the northern country's consumption [see enlarged portion, opposing page].

On average, OECD countries accounted for more than 7400 kWh per capita in 1992, whereas most of the world's countries made do with under 4000 kWh per capita. A word of caution: the OECD agency's data include all urban and rural sectors—consumer, commercial, and industrial. In the low-income countries, almost all electricity is used in urban areas, so rural people are even more impoverished than these data might suggest.

—Gadi Kaplan

Electric energy consumption in 1992 within the Organization for Economic Cooperation and Development (OECD)



Source: Organization for Economic Cooperation and Development

to lessons learned from simple technical problems. Controllers and lamp ballasts have improved, some of them locally produced; battery indicators have now become available so people can "see" how much is left in their battery (as was their custom with bottles of kerosene).

The wattage needed for rural electrification of the 2 billion people as yet without electricity can be estimated. The average load of a rural connection is around 350–500 W, so with an average family size of five and 400 million as yet unwired households, an additional capacity of 140–200 GW is needed. At a conservative grid value of \$2500/kW, this capacity would cost \$350 billion to \$500 billion. In addition, the annual fuel bills of the developing countries will be increased by \$5000 to \$10 000 million.

Governments in developing countries are already hard pressed to expand their industrial and urban capacity as fast as necessary. They will find it impossible to invest also in rural electrification. If, however, the latter task could be achieved through individual solar home systems,

the total investment would be lower, although still considerable. Assume that a 50-Wp solar home system in future will cost \$250 on average, then 400 million solar home systems (20 GWp) will require \$100 000 million, or \$4000 million annually for 25 years. These systems would have to be financed through long-term loans, not grants.

To put things in perspective, it is perhaps useful to mention the size of the predicted PV market and required capacities. Note that the present market in photovoltaics is about 60 MWp, of which about 5 MWp is for rural off-grid applications. Market analyst Paul D. Maycock, president of Photovoltaic Energy Systems Inc., Casanova, Va., expects the following markets for the off-grid rural segments in the years 1995, 2000, and 2010:

- For a business-as-usual scenario: 8, 20, and 40 MWp.
- For an accelerated growth scenario: 15, 40, and 600 MWp.

Recall the estimate that the electrification of all 400 million households currently

without electricity would require 20 GWp of PV capacity, or 800 MWp on average for a period of 25 years. This is even more than is predicted in Maycock's accelerated growth scenario. So probably this target will not be met unless bold new initiatives are taken.

BOLD IDEAS. One initiative of this nature is the Power for the World proposal put forward by Wolfgang Palz, division head of renewable energies in the European Commission's Directorate General XII, which handles science research and development. To reduce system costs and increase production volume, plants with an annual production capacity of 10 MWp must be built soon; by the year 2000, annual capacity must reach 100 MWp. This can only be done if specific conditions are met, namely, policy changes, better financing options, and system improvements. But the environmental issue must be considered right now.

There are signs of policy changes and a beginning of acceptance by electricity companies, as in Mexico and the Philippines. But there is still a long way to go before solar PV systems are accepted by utilities in developing countries as a reliable means of pre-electrification or even electrification. Sources of capital can be instrumental in changing this attitude by requesting such policy changes (as well as financing renewable options) during the negotiations for conventional power loans.

Several financing initiatives have been offered by both national and international donors; but in terms of total funds required, the efforts have to be increased by orders of magnitude. The easy terms for large power loans should be made available for small off-grid options as well.

Manufacturers, importers, and distributors should ensure the quality of their PV products. National product standards should be established, leaving enough room for product improvement.

With the introduction on a large scale of PV battery-charging systems, the number of batteries in rural areas will soar. Environmental problems could ensue if no measures are taken beforehand. Manufacturers, together with local counterpart companies, should work out optimum and least-cost solutions. National battery recycling is already in effect in Indonesia, for example.

ACKNOWLEDGMENT. This article summarizes the plenary paper presented by the author at the 12th European Photovoltaic Conference, held in Amsterdam in April 1994. The full paper has been published in the conference proceedings.

TO PROBE FURTHER. Costs of rural electrification are addressed in *Electricity for rural people* by G. Foley (Panos Publications Ltd., London, 1990) and in *Rural Electrification for Development: policy analysis and applications* by M. Munasinghe (Westview Press, Boulder, Colo., 1987).

Photovoltaic systems around the world

Country	Capacity, kW peak	Applications	Year
Argentina a	105 25 100	Telecom and buoys Institutions Other	1990
Columbia a	900 950	Solar home systems (20 000) Telecom	1990
Dominican Republic b	200	Solar home systems (4000)	1992
India c	200 100 150 100	Solar home systems and lanterns Streetlights Water pumps Power plants	1991
Indonesia d	300 340 460	Solar home systems (12 000) Telecom Other	1992
Kenya b	600	Solar home systems (15 000)	1992
Mexico a	300 170 100 100	Solar home systems (7000) Rural phones Repeaters Other	1992
Morocco e	600	Solar home systems (30 000)	1993
The Philippines f	70 35	Solar home systems Water pumping, telecom, other	1993
Sri Lanka b	100	Solar home systems (4000)	1992
Zimbabwe b	120	Solar home systems (3000)	1992

(a) Advanced Technology Assessment System, Prospects for Photovoltaics (U.N., New York, 1992).

(b) H. Hanks, Solar Rural Electrification in the Developing World (Solar Electric Light Fund (SELF), Washington, D.C., 1993).

(c) Annual report 1991–92, Department of Non-conventional Energy Sources, New Delhi.

(d) EC–Government of Indonesia 1992 Strategic Masterplan for Industrial Development in the Power Sector.

(e) Personal communication from J. Nijland, NAPS France, Paris.

(f) Personal communication from P. de Bakker, ITW, Manila.



The need for technical help in applying photovoltaics on a large scale can translate into an internationally cooperative arrangement. Witness the republic of Kiribati, a group of 33 islands in the mid-Pacific, which sought help from Japan's International Cooperation Agency (JICA). In Vietnam, too, Solarlab—the country's department for the development of solar energy—cooperated with the French company Fonder (Fondation Energie pour le Monde).



In Kiribati, then home to 72 000 people, the Japanese agency conducted a feasibility study in 1991 and subsequently installed photovoltaic systems in 55 rural households as a pilot program. Typically these systems include 2 to 12 photovoltaic panels, each with 60 watts peak power (Wp). Installed on poles, the panels charge batteries to supply light at night [photos, bottom]. Encouraged by the pilot program's success, Kiribati's Ministry of Works and Energy is planning the electrification of 1250 additional households, as well as 250 other systems for schools and clinics.



In Vietnam, Fohdem provided photovoltaic panels for Friendship Vietnam-France Solar Station in the district Duyen Hai, while Solarlab supplied electronic hardware and took care of installation, management, and maintenance. Solarlab installed a similar but smaller solar station (200-Wp) on the island of Condao [top, left], and a 1000-Wp system for the solar station and cultural house in Tayminh province [top, right]. The house serves both as a cultural center in remote areas and as a demonstration of photovoltaics capabilities.

At the heart of the system is Solarstat, a 1-kWp system with five channels. Four are for charging batteries for individual households, and the fifth supplies power for the cultural house's activities. —G.K.

R.J. Saunders is the author of "The World Bank's role in the electric power sector: policies for effective institutional, regulatory and financial reform," a 1993 World Bank Policy Paper, published in Washington, D.C. The costs of electrification are discussed by R. Turvey and D. Anderson in *Electricity Economics*, a World Bank Research Publication (Johns Hopkins University Press, Baltimore, Md., 1977).

A reference to an early photovoltaic system in Chile is included in *Photovoltaics for Development*, by R. Hill (ed.), United Nations ATAS Bulletin No. 8, 1993.

Integrated Rural Energy Planning was discussed by Y. El Mahgary and A.K. Biswas in a United Nations Energy Planning (UNEP) publication (Butterworth Scientific, England, 1985).


Solar home systems are discussed in *The Philippines' Rural Photovoltaic Electrification Scheme* by G. Santianez-Yeneza and H. Böhnke in a publication of the National Elec-

trification Administration, Manila, 1992. Photovoltaics applications were addressed by R. Schröer and P. de Bakker in their article, "It All Began on Burias Island," *GATE* magazine, July 1989. *Solar Rural Electrification in the Developing World; Four Country Case Studies: Dominican Republic, Kenya, Sri Lanka, Zimbabwe* was dealt with by M. Hankins, Solar Electric Light Fund, Washington D.C., 1993.

The financing of energy services for small-scale energy consumers (Finesse) was discussed during the World Bank workshop, Kuala Lumpur, October 1991. Paul Maycock examines *Photovoltaic technology, performance, cost and market forecast 1975-2010*, in a publication of PV Energy Systems Inc., Casanova, Va., June 1993.

Bold initiatives in rural electrification were proposed by Wolfgang Palz in his paper "Power for the world," which is to be found in the proceedings of the International Solar Energy Society (ISES) Solar World Con-

gress, held in Budapest in 1993.

Energy sources are regularly written about in the papers in *IEEE Transactions on Electron Devices*, while energy conversion by renewable sources is regularly addressed in *IEEE Transactions on Energy Conversion*. 

ABOUT THE AUTHOR. Erik H. Lysen is head of the department of new developments, built environment in Novem, the Netherlands' Agency for Energy and the Environment, Utrecht, the Netherlands. He has been involved with renewable energy for developing countries since the mid-'70s. He a long-time energy advisor to the Netherlands Ministry of Foreign Affairs, and has carried out consultancy missions to many developing countries, as well as missions for the World Bank and the Asian Development Bank. In his present position he is responsible for the Dutch national solar R&D program, and he is Board member of the Dutch section of the International Solar Energy Society.

Water from the African sun

Widespread application of photovoltaics in the drought-prone Sahel region brings forth water and a wealth of practical knowledge as well

The most ambitious world-wide program in photovoltaics ever financed by the European Union (until a year ago, the European Community) is nearing realization. Its goal is to better the living conditions of those who live far from population centers. Both short-term and permanent improvements are envisaged.

The first task is to make available drinkable water [Fig. 1], the next to irrigate fields under cultivation. A third aim is to supply small communities with electricity for lighting and essential refrigeration. As part of this 1200-kW (peak power) project, Siemens Solar GmbH faced special requirements involving a variety of systems and key components. The project had several important social aspects as well.

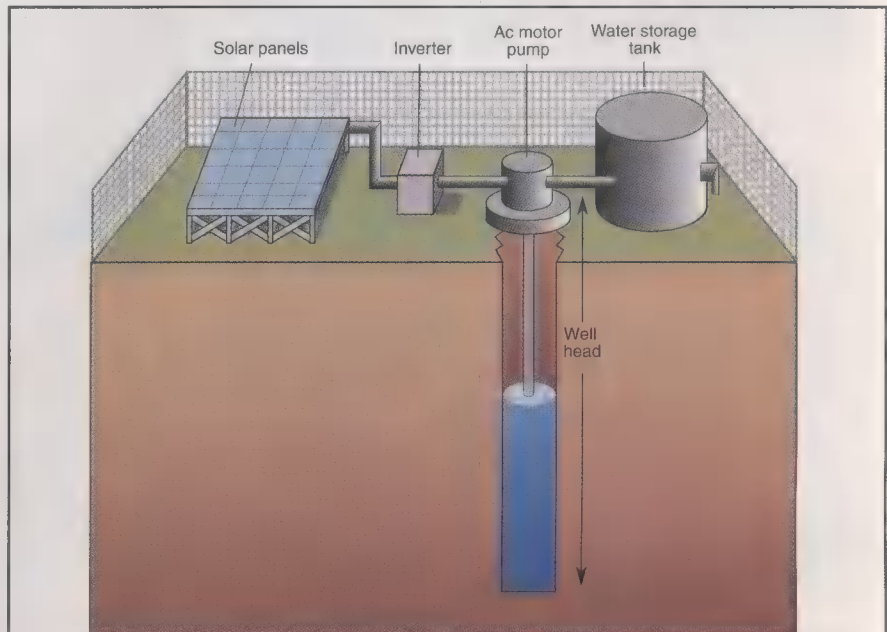
The project's beneficiaries are the members of a body set up in 1973 to fight drought in West Africa's Sahel zone, the Comité Inter-Etats de Lutte contre la Sécheresse dans le Sahel (Cilss). Present membership consists of nine countries that suffered greatly from drought in 1968 and 1974: Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, and Senegal.

It was to help these nations that the Programme Régional Solaire (PRS) was established to make use of photovoltaic energy and to that end given 34 million ECU in funding by the then European Community as nonrepayable aid.

The program was divided into three parts, with Siemens Solar GmbH the first to be awarded a contract. The contract called for systems to be installed in five Cilss states—Gambia, Guinea-Bissau, Cape Verde, Mauritania, and Senegal. All in all, Siemens Solar will supply 550 kW, peak, of solar power. Most of this power will be used by 330 pumping systems [Table 1],

Serge Makukatin

Siemens Solar GmbH



[1] In a typical water-pumping system, such as this one in Guinea-Bissau, an inverter converts the dc output generated by an array of solar panels into the ac power needed to run the pumps. The characteristics of the well and community requirements determine the type of pump and solar-generated power at each installation.

the largest number of high-capacity pumping systems of any part of the program.

Also to be provided are a total of 339 so-called community systems—240 for lighting, 63 for refrigeration, and 36 for recharging lead-acid and nickel-cadmium batteries [Table 2]. The DM 30-million contract covers parts supply, installation, mainte-

nance, and after-sales support.

Under this contract, Siemens Solar had in addition to establish a service network, train local partners, and support their activities. The execution and coordination of this all-embracing contract required the establishment of a complex project organization. For instance, Siemens was obliged to find a local

partner in each of the five countries.

These partners would be responsible for maintaining contact with the local building supervisors, coordinating all essential documents (dealing with orders for installations and technical information resulting from alterations) and dispatching them to Siemens, and stocking spare parts for repairs. The importance of reliable local partners cannot be overemphasized. A lack of spare parts or technical support has wrecked many a past project.

Numerous companies volunteered for the project. The challenge was to identify those that would be most suitable as partners. In the end, there were only a few serious candidates with adequate financial backgrounds.

The partnership benefits both parties. By being involved in the greatest PV project ever carried out, the local partner can earn a good sum of money for the services rendered. Siemens Solar, in turn, can extend its activities in the African market through the aid of the local partner.

For its partner in the Sahel region, Siemens Solar chose a French company that had already been a subcontractor on African projects, successfully performing installation and maintenance services. Wherever it has a local subsidiary in the five regions, Siemens' partner takes care of any tasks there directly. Otherwise, it picks a company in the area to do so.

FUTURE UPKEEP. As the main contractor, Siemens has to guarantee all systems and to deliver spare parts for five years free of charge (although consumable materials, such as light bulbs, have a one-year-warranty). After the termination of the five-year guarantee, funds will be needed for maintenance and replacement.

Once a village has inspected and provisionally accepted the PV system, those of its inhabitants who use it pay an annual sum determined by the individual system's maintenance costs. For example, a medium-sized P4 pumping system used in Mauritania will deliver 9000 m³ of water in a year. Dividing the total US \$2000 yearly costs of maintenance (\$900) and replacement (\$1100) by the annual 9000 m³ water output, results in 22 cents per cubic meter of water. This is the charge users must be able to afford to keep the system operational; it does not include money for new investments in future PV plants.

Siemens chose its own M50 module, a 50-W, peak, monocrystalline solar panel with an efficiency of 12.4 percent, as the major power component. A requirement of the EC project is that all components be of European origin.

The key components for pumping systems are the pumps themselves and their ac inverters. Standard centrifugal pumps and motors are used for high water output [P5 and P6 in Table 1]. These pumps are equipped with 3.5-kVA Simovert-P-Solar

1. The performance of different types of pumping systems

Pumping systems		Hydraulic energy cubic meters per day	Nominal well head, meters	Water flow cubic meters per day
Type	Sub-type			
P1	1	180	5	36
	2		7	25
P2	1	340	5	68
	2		15	22
P3	1	360	20	18
	2		30	12
P4	1	820	20	41
	2		30	27
	3		45	18
P5	1	1340	20	67
	2		30	44
	3		45	29
P6	1	2050	20	102
	2		45	45
	3		75	27

inverters. This inverter model—a slightly modified version of the more than 10 000 units thus far produced by Siemens—is designed for highly reliable operation even under severe conditions. It has an efficiency of up to 95 percent.

The Simovert-P's microprocessor allows it to be programmed for special site conditions. It drives common three-phase, 220-Vac pumps up to 2.2-kW rated power. There are no known competitive inverters with these features.

Centrifugal pumps with modified motors are employed for the smaller pumping systems (P2-P4). The Grundfos Solartronic SA1500 inverters drive the modified three-phase, 65-Vac pumps. (The P1 types are for surface-pumping irrigation systems.)

Both Simovert-P and the Solartronic inverter have dry-running protection and can produce frequencies from 1 to 60 Hz. The actual output frequency at which the inverter operates depends on several factors: the input power from the solar modules, type of pump, piping, and the delivery head (defined as the height of the inlet to the cistern above the well's water level). The efficiency differs with frequency and also with pump type, piping, and the slope from the delivery head. Typical efficiencies of the combined inverter, pump, and motor are in the area of 40 percent at 50 Hz and 10-20 percent at 25 Hz.

DANGER-FREE. The installations need to be safe in two senses. They must be as immune as possible to external events, like lightning strikes, as well as harmless for people to approach and maintain.

There are two types of lightning protection: external and internal. The external variety

consists of connecting all parts (not only the modules and inverters, but also the support structures and fences) to earth ground. This is accomplished by burying a ring of copper cable 1 meter deep in the ground around the system and inside its protective fence, and connecting the ring to an earth-pole, or plate, in the ground. These measures ensure that, in case of an external overvoltage, no significant difference in electric potential exists between the different components.

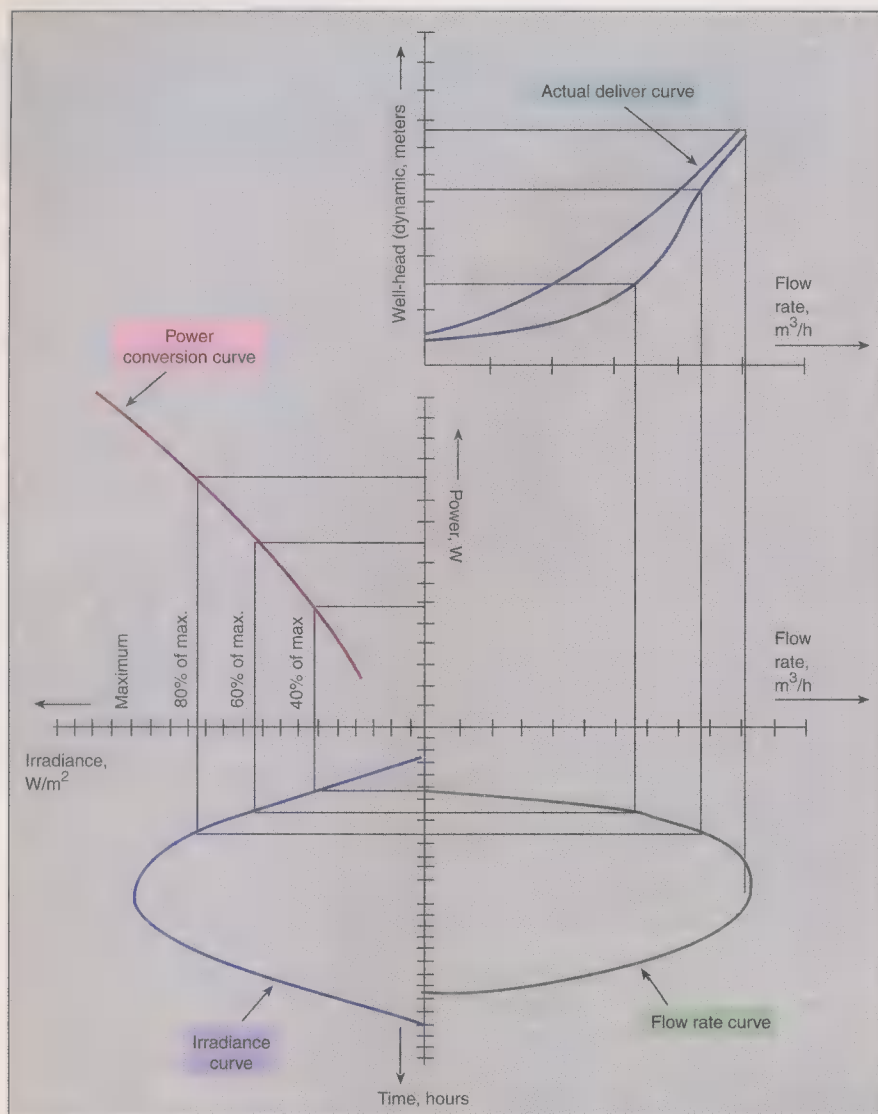
The internal protection keeps any overvoltage from damaging the electronic devices—the inverter and solar-cell array. It consists of varistors in the junction box and in the inverter.

Since the operating voltage of the pumping system lies in a hazardous range, measures must be taken to protect the public as well as system maintenance personnel. For this reason, the systems were designed using German industrial safety standards (DIN/VDE-Standards). In addition, each pumping system is fenced off from the public.

The EC office awarding the contract imposed strict quality requirements on components and material for this project. It

2. Community photovoltaic systems

Applications	Peak power, W _p	Number installed
Lighting 3 fluorescent lamps 8 fluorescent lamps	50	173
	150	67
Refrigeration Medical refrigerators	300	63
Battery chargers For nickel-cadmium For lead-antimony	100	15
	200	21



[2] The first curve [reading counterclockwise from upper left] is the power irradiance indicating the correspondence of solar irradiance with maximum power output of the solar generator. The next curve shows the irradiance at a specific time of day. In conjunction with the first curve, it reveals the power output of the generator at a specific point in time. The third curve, which charts the water's flow rate, can easily be linked to the other two. Last is the diagram of the output at the water delivery head, which charts the characteristics of the pump and the well in relation to the amount of water delivered.

wanted to ensure that systems would be rugged enough to operate in harsh environments throughout a long service life.

To find accessories and components of suitable quality at acceptable prices, extensive market research was necessary. The materials and components selected had to pass severe tests performed at one or other of the four European research laboratories that are officially accepted by the Cilss organization: Technical Inspection Authority (TUV) Rheinland, Cologne, Germany; LVT/CEA, Cadarache, France; Global Renewable Energy Services (GRES), Swindon, England; or Ciemat, Madrid, Spain. The main purpose of the tests was to ensure that the technical data indicated by the suppliers reflected the

specifications required.

For instance, in the case of the inverters, the test criteria used by TUV Rheinland included performance, efficiency, temperature and climate tests, electrical safety, and the examination of packaged devices after a drop from a height of 1 meter. Further, the fabrication processes of the inverters' suppliers were audited. During these tests, some possibilities for optimizing the devices came to light and were later integrated during production.

For instance, the degree of electrical protection was increased from IP54 to IP55, the mechanical mounting of several components was optimized for greater ruggedness, and the steering program within the microcontroller was improved.

A 10-g vibration test was also added to production testing.

Although this testing raised the supplier's costs, in the end it was justified by the way the components operated; all devices work perfectly in the field and are highly reliable, which is not typically the case for photovoltaic inverters.

For all PV modules, a certificate (CEC specification 502) from the Ispra Institute of Ispra, Italy, is proof of qualification for the project. No problems arose in complying with the module data for any of the PV systems during the verification of the delivered power.

For the West-African region, the basis for the system design is 6 kWh/m² per day (which lasts from 6 AM until 6 PM there) and a daily output of water within a range of 30 percent (-10 to +20 percent). All design values (300 W, peak, to 3.8 kWp, rated generator power) were checked and confirmed by the customer.

For a specific site on an average day in a recommended month, a nomograph can be used to determine the characteristics of a photovoltaic pumping system (of the solar generator, the well, and the water output) [Fig. 2]. Note that when water is drawn, its level in the well will drop; this so-called draw down and the rate at which the water returns to its previous level depend on the conditions of the site. No realistic statements on the delivery capacities of the systems can be made without these data. On this basis, characteristic variations for various frequencies [Fig. 3] were determined for all centrifugal pumps used.

FIRST RESULTS. The first of the project's PV pumping systems were installed in early 1991. As of April of this year, 55 out of the total of 330 deep-well pumping systems had been installed and had provided approximately 270 000 hours of trouble-free operation. The total efficiency (from sun to water) of the completed systems is about 3-4 percent. The efficiency of other systems is about 2-3 percent.

All systems work without any notable problems, so that the local populations can rely on receiving the precalculated quantities of water. The yield of the systems until now amounts to approximately 1 200 000 m³ of water and is probably unique in its volume. In several villages the water output is so great (50-60 m³ per day) that the cisterns can be filled up within two or three hours.

Cilss has installed several test PV plants that store all key data: delivery head, water output, insolation, voltage/current of solar generator, and water output. The goal is to measure performances and water output within a limited time period. So far, the stored data has shown that the systems' output exceeds the Cilss specifications by 10-20 percent (water output per day at a specific insolation).

As of April 1994, 30 of the 339 communi-

ty systems had been installed, among them 11 cooling systems used for storing vaccine in Mauritanian first-aid hospitals and 6 lighting systems in Cape Verde schools. All the installed systems have satisfied their users and work without trouble.

Essential to this success were the contributions of the local companies. Following a period of well-structured instruction, these local companies assembled, installed, and maintained the pumping systems.

In this way, an excellent base of technical knowledge for system and component has been established within the Cilss organization. The local firms involved with the systems are now familiar with PV systems and their experience should form the basis for further successful applications in this and future projects.

MINOR PROBLEMS. As with every project, there were some problems, but they were minor in nature. Some Gambian systems are in a region with frequent lightning strikes. To date, four lightning barriers at the input of the 3.5-kVA inverters have been destroyed by indirect lightning strikes. Nevertheless, the devices fulfilled their function because the inverters remained fully operational. The barriers were replaced with locally available spare parts.

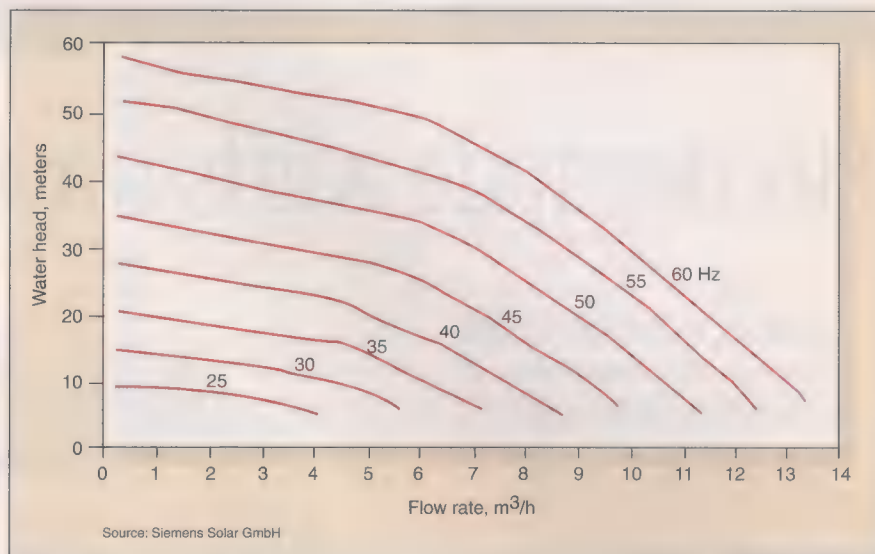
The second event, and to date the last, was the failure of four float switches in boreholes, caused by corroding well casings. The problem was remedied by using an additional float switch filter.

CHOICE OF VILLAGE. The selection of a village to be equipped with photovoltaic systems is governed by several criteria. There must be a real demand for water supply (population) and the basic infrastructure must be there (water hole, a small hospital). In addition, the villagers must be able to pay some money for replacement and maintenance. The water committees of the local villages take care of the administration of the money. Fees for the water can be individually paid if somebody takes water. Alternatively, it is also possible to pay an annual average per family.

Payment for the water is essential—it ensures the survival of the PV system. In Cape Verde, droughts have often lasted for as long as two years. When this happened, the villagers had to pay for water brought in tanks from the capital or places with higher rainfall. It was not difficult for these people to understand that water is not free of charge.

The Podor people of Senegal, on the other hand, have traditionally taken drinking water from the river free of charge. Even although this water was often polluted and caused many diseases, it is difficult to explain to the people that they must pay for clean drinking water. So the need to pay for water must often be clarified in lengthy discussions.

PV systems within the region have completely changed the lives of the African vil-



[3] A nomograph for each type of pump lets engineers determine the frequency at which it must be run to deliver the desired hourly flow of water for a given well head. However, each well has its own draw-down—a lowering of the well's water level caused by drawing water at a particular rate. This affects the amount of water delivered and must be taken into account.

lage people. Infectious diseases caused by polluted water have greatly diminished. Pure drinking water is available at water taps, and women and children no longer have to walk 3–5 km for water. Freed from this chore, children can go to school while women can tend a kitchen garden watered by the PV system. Because of the electrification of schools and public buildings, it is now possible to educate people after the workday ends at 6 PM.

In each case, the local population must recognize the need for a village organization that is responsible for seeing that the PV installation is kept in good condition. They must also realize that they, too, have an obligation to care for the systems; there cannot always be a solution from an external source for everything.

To solve the problem of collecting money, several sociologists, who are working on the problem of forging an "identification of people with the project," have in the meantime worked out insurance concepts. For example, in Gambia—a relatively well developed country with good business opportunities—a contract being negotiated between the Department of Water Resources and an insurance company covers the possible risks of maintenance and replacement. This had the advantages of lowering costs for maintenance and replacement and of placing financial administration outside the village.

PRELIMINARY FINDINGS. Three years into the project, some interim conclusions can be drawn. Because of its comprehensiveness—including the high requirements set on system quality and the reliance on local firms and local after-sales service, the training of local partners, and the stocking of spare parts within each country—the project is very likely to succeed and to set an

example for others like it in the future.

Photovoltaic systems have proved to be a reliable way of offering essential services to rural communities off the electric grid. But for the successful implementation and operation of such systems, well-trained partners located in the developing communities are imperative.

That the components used in the project have shown themselves to be reliable and of high quality indicates that authorized inspection institutions play an important role in the success of large-scale projects. At the same time, projects like Cilss allow manufacturers and suppliers to optimize their systems and components and prove their reliability. This in turn is beneficial for the next customers, increasing confidence in the products.

Last, but by no means least, the Cilss project clearly demonstrates the benefits of appropriate technology to people in remote areas.

TO PROBE FURTHER. More information about this project can be found in the paper, "PV Energy for a Sustained and Social Development in the Sahel Region," by F. Kabore, in *The Yearbook of Renewable Energies*, a publication of Eurosolar in collaboration with UNESCO sponsored by the Commission of the European Communities, 1994, pp. 146–149.

ACKNOWLEDGMENT. The author thanks Mr. Cunow and Mr. Theissen, engineers from the technical office of Siemens Solar, for their valuable support.

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Homemade watts for rural India

Subsidized by the government, about 62 000 stand-alone photovoltaic systems supply villages with power for light, TV, radio, and pumping water

Being noiseless and environmentally benign, systems for turning sunlight into photovoltaic energy could well become an important source of electricity. As yet, electricity from a utility is less expensive, but it is not always available. That makes solar photovoltaics (PV) competitive in the far corners of many countries, mostly in the developing world.

Terrestrial applications of solar PV have come a long way since serious work on them was triggered by the oil crisis of 1973. Over the years, India has kept up with international activities and development in this area. The reasons are obvious. The subcontinent's plentiful sunshine and widely scattered rural population are well adapted to a source of electricity whose cost per kilowatthour compares favorably with the cost of expanding the electricity grid into remote areas.

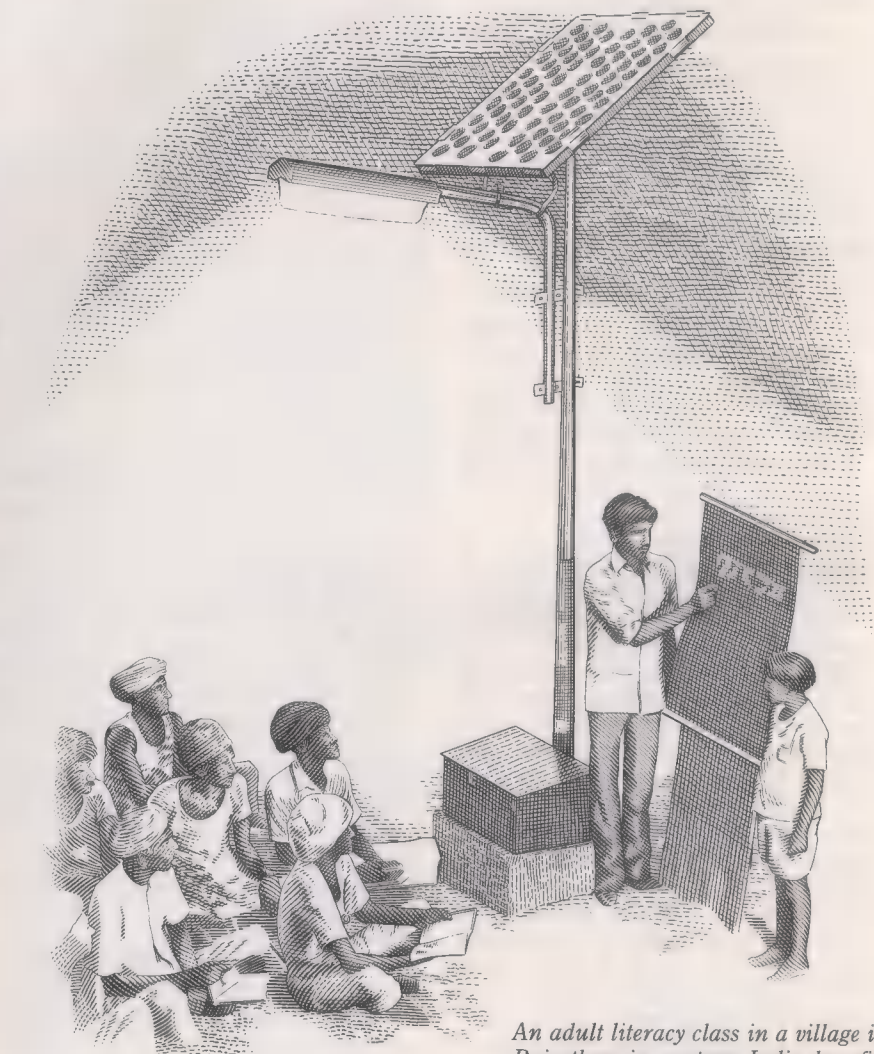
In India today, as in other developing countries, PV systems serve to pump water for villages and to supply the villagers' homes with power for lighting, radio, and television. Commercially, too, they are used to power remote communications and off-shore systems.

Last year, India's shipments of PV modules totaled more than 4 megawatts, peak, constituting about 7 percent of international shipments. (The peak watt, or Wp, is the power produced by a PV module under standard test conditions: 1 kW/m² at air mass 1.5 incident solar radiation with a solar cell operating temperature of 25 °C). Indian module shipments should exceed 7 MWp this year, for a turnover of about 2000 million Indian rupees (US \$65 million). This would account for more than a tenth of the total world shipment of modules.

The fast growth of the Indian PV industry has also attracted growing technological and equity participation from other

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Consultant



An adult literacy class in a village in Rajasthan in western India benefits from an outdoor lamp powered by a photovoltaic system.

countries. Many leading companies in this field from the western world now have a presence in India.

STAND ALONE. Without exception, Indian PV applications are stand-alone, a necessity when there is either no or not enough utility electricity available. A typical stand-alone system consists of the PV modules, a bank of storage batteries to handle the load when there is no sun, and assorted mechanical, electrical, or electronic components making up the balance of the system. The components vary with the system's application, but usually include mounting structures for the modules, wires and cables, meters, switchgear, indicators, fuses, and electronics for battery charge control, dc-to-ac conversion, and energy management electronics.

India's rural PV applications have by and large been planned to supply power for essential domestic or outdoor lighting, communications, pumped water, or a combination thereof, more or less uniformly distributed geographically.

At present the applications fall into four categories: portable lanterns operating for a few hours an evening and using a 5- or 7-W compact fluorescent lamp; one- or two-light domestic systems, with or without television receivers; systems for pumping drinking water from deep wells or water for irrigation from shallow wells; and village power plants, up to about 25 kWp in

Artist: Harry Bates. (Based on photos supplied by Central Electronics Ltd., Sahibabad, India)

capacity, dedicated to the lighting, water-pumping, and TV reception requirements of the community.

PLANS AT THE TOP. The Government of India has long planned to phase in various forms of renewable energy sources, including solar PV, or at least to do so in remote parts of the country unlikely to link up with utility power for many years. But the prices of photovoltaic systems and components are relatively high. So the powers that be decided that solar PV systems could not be introduced commercially at this stage without their financial support.

The government therefore undertook to finance demonstration projects fully during the last decade, a phase in which valuable field experience and data were gathered. That phase was gradually changed to one in which the consumers met a part of the costs for PV electrification, generally through periodic payments. However, the government still paid the bulk of the costs. Indeed, it still pays them in economically backward communities and many all-but-unapproachable regions of the country. Elsewhere, the financial support is slowly taking the form of soft loans to consumers with easy payment terms—the loan is to be paid back within eight to 10 years and the interest rate is lower than the prevailing market rate.

A case in point is a nationwide project for 1000 water-pumping PV systems for drip and sprinkler irrigation. The Indian government launched the project and shoulders up to 70 percent of the system cost, pro-

viding the consumer with a soft loan at low interest to pay for the rest.

Under the program, about 62 000 stand-alone rural PV systems have already been installed. Half are outdoor, single-fluorescent-light systems. Another 20 000 or so are one-, two-, or multi-light indoor lighting systems with or without a TV receiver. (A literally instructive application has been the installation in distant regions of a few thousand indoor two-light systems, to help in teaching adult day workers to read.) Finally, a few thousand portable PV lanterns, a thousand pumping systems for shallow and deep wells, and close to 500 small stand-alone village power systems have also been installed. All of these systems have been produced and engineered in India.

MARKET PROGRAMS. In addition, a commercial market for solar PV is opening up in India. Recently, many market-oriented PV programs have been launched, including one using a \$42 million World Bank credit. This revolving fund offers soft loans with easy repayment terms to likely users of PV systems. The market development program is the first ever financed by the World Bank in the area of renewable energy. Detailed technical performance specifications and bid documents for stand-alone PV systems have been prepared for international competitive bidding. A publicity campaign to enlarge consumer awareness has also been launched.

The first commercial Indian application of PV was in 1983. Its job was to supply

energy to the on-board electronics of offshore well-head platforms in the Arabian sea.

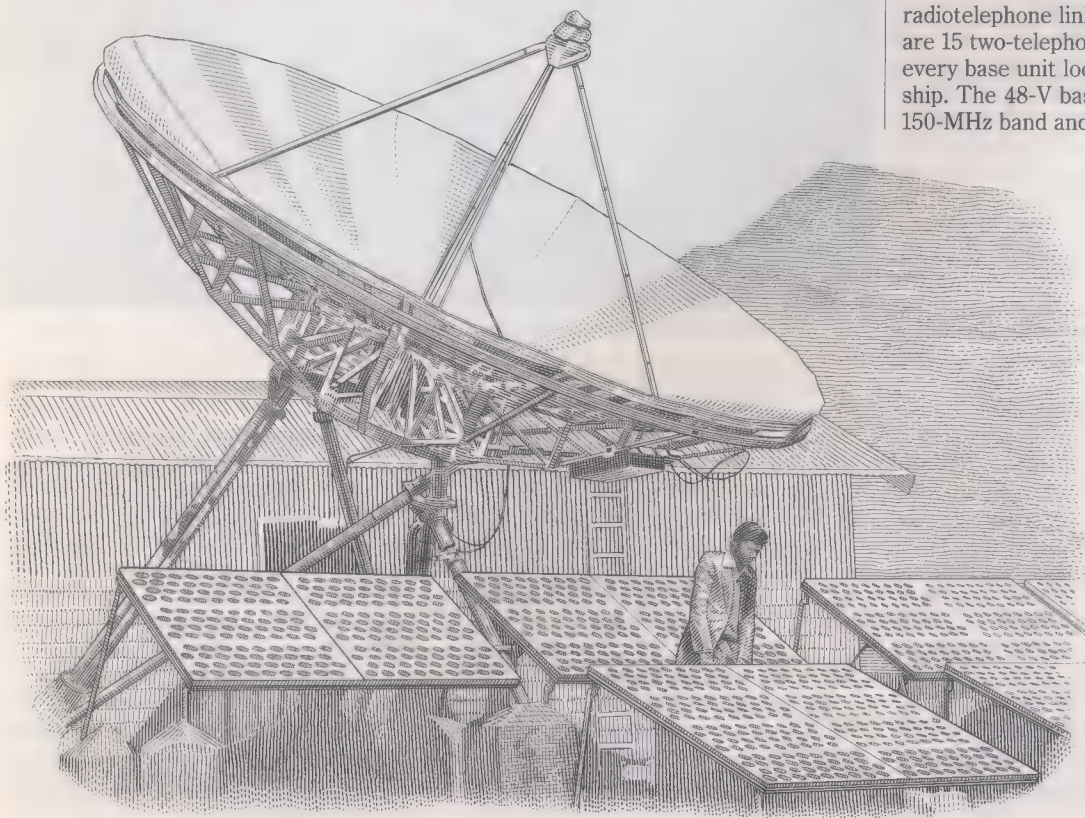
Other applications soon followed in the fields of communication and telemetry, transport, oil, meteorology, defense, and so on. It should be appreciated that the government is also a consumer and buyer in these market sectors.

With the installation of 75 more very low-power TV transmitters by December, there will be 200 of them in operation in places cut off by natural obstructions and shadowing from standard TV transmitters. About 30 percent are situated in areas where utility electricity is available but is intermittent and of unacceptable quality. The remainder are located in unelectrified areas.

Each transmitter is designed to operate in a completely unattended mode. It consists of one operating and one stand-by 10-W transmitter, a TV receive-only antenna for picking up satellite signals, and a transposer. The mean daily energy consumption is about 3600 Wh at 24 V dc. A six-day storage autonomy is built into the 1.7-kWp PV system.

Each transmitter covers an area with a radius of about 10 km. In conjunction with a few thousand solar PV-operated direct TV receiving sets (DRS) and standard TV receivers, the very low-power transmitters are helping to extend the national television network to every nook and cranny of the country.

RADIOTELEPHONE LINKS. The most notable commercial application in recent years has been the use of PV to power remote VHF radiotelephone links all over India. There are 15 two-telephone links of this kind for every base unit located in a nearby township. The 48-V base unit operates on the 150-MHz band and is generally energized



This technician is inspecting the photovoltaic modules that power a very low-power television transmitter and antenna located in the foothills of the Himalayas in northern India.

by utility electricity. Each remote village link is operated by a solar PV system having ■ module capacity of 70 Wp and a deep-discharge, 12-V, 120-Ah battery. About 60 000 rural telephone links of this kind are now being installed and a further 30 000 systems are being procured.

The idea is to energize all such rural telephone links with solar PV electricity. It is quite often possible to infer the remoteness of the installations from the fact that, in many places, the cost of transportation and installation exceeds that of the PV energizing system.

Following extensive and extended qualification testing, the Indian Railways are now using stand-alone PV systems in many applications, among them semaphore signaling, automatic radio-controlled audio-visual alarms for level crossings, and small-wayside-station electrification to replace diesel generator sets. The PV-powered semaphore signal lighting has proven to cost much less than kerosene light.

Elsewhere, ■ number of PV-operated cathodic protection systems have been installed for oil-carrying pipelines. There are many similar applications of solar PV in the meteorology and defense sectors. Recently, a collapsible, portable PV module, with integrated battery-charging electronics, was introduced in large numbers in the army, after extensive qualification tests and field trials.

Undeniably, field problems have arisen with many rural and some commercial PV systems. They are generally of two types: those due to vandalism and pilferage from publicly owned systems, and those due to technical and design defects.

Technical failures have generally been manifested in the malfunction of electronic balance-of-system components, such as dc-to-ac converters and battery-charge controllers. The storage battery, too, often failed, frequently owing to the failure of its control electronics. Many times, for example, the components selected are not properly qualified to work in a harsh outdoor environment.

For publicly owned systems, the lack of simple maintenance, like the topping-up of the storage battery, also resulted in catastrophic system failure. Occasionally, system failure was due to inadequate system sizing by the supplier. However, the PV modules rarely failed.

Of late, technology upgrades, with inputs coming from outside as well as inside the country, and the advent of ■ competitive market have considerably improved the performance of PV systems in the field. This, in turn, has helped the decision makers to appreciate the potential of solar PV. In short, Indian achievements in the rural application of solar PV have been due to the commitment of the Indian government and ■ few technical organizations. The existence of an industrial base, highly

Solar photovoltaic installations in India

System application	Description	Estimated no. of units
Rural		
Stand-alone, pole-mounted, outdoor lighting	25–70 Wp (peak watts) 3–6 hours per day; 20/18-W fluorescent or 11-W compact fluorescent lamp (CFL)	29 230
Indoor domestic lighting	70–300 Wp; 3 hours to all night; one to three lights; 5-, 7-, or 9-W CFL	14 430
Indoor domestic lighting plus TV receiver	As above, but with a black and white or color TV receiver ; 100–300 Wp	3750
Shallow-well pumping for minor irrigation	Water table up to 7 m; 300–1200-Wp capacity; no battery storage	1250
Deep-well pumping for drinking water	Water table: 10–130 meters; 1- and 5-kWp capacity; overhead tank storage	315
Portable lantern	6–10 Wp; 3–6 hours per day; 5–7 W-CFL	8900
Vaccine refrigeration	15–100-liter capacity; World Health Organization specifications	186
Direct-from-satellite TV receiving sets	100–300 Wp; color TV with dish antenna and electronics	1800
Village power supply	1–25-kWp capacity (loads include lighting, fans, TV receivers, and water pumping); sized for specific location and loads	486
Miscellaneous	10–200 Wp	675
Commercial		
Unmanned very-low-power TV transmitters	1.7–2.0-kWp photovoltaic array; 24-V, 1600-Ah deep-discharge battery; two 10-W TV transmitters and one TV receiver	
Energizing electronics on board offshore well-head platforms	2–3.5-kWp capacity; qualified for marine environment	38
Multi-access rural radio communications	70–90-Wp modules; 12-V, 120-Ah battery	1820

Source: Various organizations in government and industry in India.

trained technological manpower, and plentiful sunshine in most regions have also contributed to the success. Indeed, the future of solar PV appears bright in India as in many other countries.

TO PROBE FURTHER. India's ongoing effort to use technology and science systematically for the health and well-being of its people is discussed in *IEEE Spectrum's* special report "Technology in India," March 1994, pp. 24–53. The report recognizes electric power as a government priority.

Photovoltaic applications are addressed in "Solar Technologies in India," published by the Ministry of Non-Conventional Energy Sources, Government of India, New Delhi, December 1993, and in the 1992–93

and 1993–94 Annual Reports of the same ministry.

ABOUT THE AUTHOR Tapan Kumar Bhattacharya is now a consultant to various organizations on solar photovoltaics. From 1977 to 1986, he was the leader of the solar photovoltaics team at the Central Electronics Ltd. (CEL) organization originated the PV movement in India. Recently he wrote the performance specifications of stand-alone PV systems for the World Bank program. Earlier, he wrote detailed guidelines for stand-alone PV system design, a computer program on system sizing and simulation, and a popular science book on desktop personal computers. He has been a visiting professor in a number of Indian educational institutions.

Europe's supercollider project

With the U.S. supercollider dead, the project's orphans are scrambling to get aboard Europe's proton-smashing Large Hadron Collider



At the end of 1993, after 10 years of controversy that had left the U.S. physics community bitterly divided, the U.S. Congress canceled construction of the Superconducting Supercollider in Waxahachie, Texas. The

SSC, as it was known, would have been by far the largest and most energetic particle accelerator ever built, a technological and scientific triumph that was intended, among other things, to recover for the United States the lead in particle physics from Europe.

Instead, European particle physics has emerged stronger than ever. At a meeting tentatively scheduled for late September (as this article goes to press), the governing council of CERN was expected to authorize construction of the Large Hadron Collider (LHC). This facility will be a smaller version of the SSC, and is to be built at much lower cost, although at higher technical risk, than the planned U.S. supercollider. It will be housed in an existing accelerator tunnel straddling the Swiss-French border outside Geneva at CERN (originally the European Center for Nuclear Research, now known as the European Laboratory for Particle Physics).

Like the SSC, the LHC is intended to smash protons against protons at energies sufficient to reveal the nature of matter and to consolidate the prevailing general theory of elementary particles. But whereas the Texas collider would have crashed proton beams of 20 trillion electron volts head-on, for an effective collision energy of 40 TeV, the LHC is now planned as a 14-TeV (total collision energy) machine. That figure still beats the present best: the most energetic proton collider now in operation is the Tevatron at Fermi National Accelerator Laboratory in Batavia, Ill., in which beams collide with an effective energy of about 2 TeV.

The energy of the European collider

William Sweet Contributing Editor

should be enough to prove the existence of a crucial but arcane particle called the Higgs boson (or bosons). Success would achieve one of physics' long-sought-after goals: an understanding of why certain fundamental particles have mass—and an accounting of what matter is and what causes it to exist. Such an outcome, however, will require completion of one of the most technologically demanding projects ever undertaken in physics research. The LHC's particle detectors, superconducting magnets and associated cryogenics, and data collection will all demand achievements at the very edge of what is technically possible.

A special prestige attaches to particle physics. If, therefore, the LHC is built as planned, it will be widely taken as proof that Europe has recovered its age-old position at the center of world science. That probable outcome can be laid partly at the door of the physics leadership of the United States, which has not always exercised the best technical and political judgment.

COMPETITIVE INSTINCTS. The goal of building a supercollider is to confirm the final major details of what is known among physicists as the standard model of the fundamental particles and their interactions. The idea originated in the early 1980s, at a time when competition between the U.S. and European particle physics communities suddenly heated up.

The cause was the discovery, in 1983 and 1984 at CERN, of the W and Z particles, the relatively massive carriers of the weak interaction. The feat definitively confirmed the union of the electric and weak forces, two of the four natural forces regarded until then as distinct (the others are the strong force

and gravity). It also won the 1984 Nobel Prize in Physics for Carlo Rubbia and Simon van der Meer. Rubbia conceived and led the project, and van der Meer invented the technique that enabled CERN to build the innovative proton-antiproton collider with which the particles were first observed.

A controversial figure, Rubbia is known not only for his ego and drive but also for his mastery of electronics. He was considered an electronics wizard from early childhood, according to a not always flattering but largely uncontested account by science journalist Gary Taubes in *Nobel Dreams* (Random House, 1986). Taubes writes that Rubbia "still remembers the day the newspapers announced the invention of the transistor as a great day in his life," and "was always aware of the latest technology" and "ready to risk everything to use it."

A proton-antiproton collider has beams circulating in opposite directions but guided by the same magnets. In the mid-1970s Rubbia was alerted to the possibility of constructing one by a young physicist named Peter McIntyre. In 1978, Rubbia, McIntyre, and physicist David Cline (then at the University of Wisconsin) tried to sell the idea to Robert Wilson of Fermi National Accelerator Laboratory, or Fermilab, but they were rebuffed. It seems that diplomatic errors in the approach to Wilson were compounded by Rubbia's then dubious reputation and Wilson's mistrust of him, and by general fiscal conditions.

But whereas the Vietnam War had left U.S. physics strapped for funds, CERN happened to be flush. Rubbia went straight there from Fermilab, sold the laboratory's leadership on the idea of converting an existing accelerator into the world's first

Defining terms

Baryons: particles, such as the proton, antiproton, and neutron, consisting of three bound quarks.

Bosons: the force-carrying particles, that is, the massless photon and the very heavy W⁻, W⁺, and Z particles.

Cyclotron: the kind of accelerator, invented by Ernest Lawrence, in which particles spiral out from the center of a ring under the influence of a magnetic field at right angles to their paths.

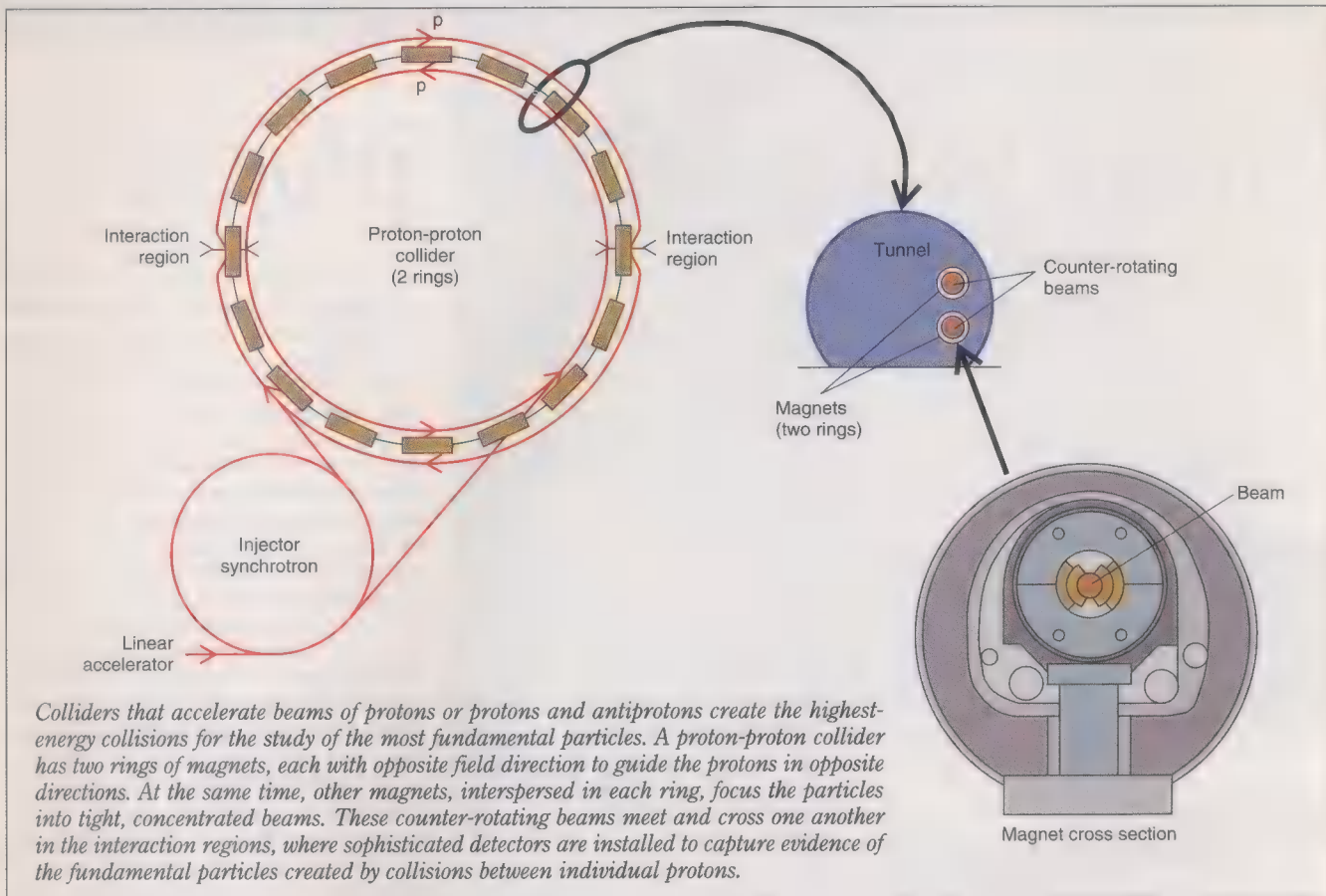
Electroweak theory: the unified theory that accounts for the electromagnetic force and the weak force, which is responsible for radiative decay.

Fermions: the elementary constituents of matter, including the six quarks and their antiquark partners, and the electron, muon, and tau and their partner neutrinos.

Hadrons: the particles consisting of quarks that are affected by the strong force.

Mesons: "bosonic hadrons," these consist of two bound quarks and include the kaon and pion.

Synchrotron: the standard contemporary accelerator, in which particles are guided in a circle by magnets and repeatedly sent through radiofrequency cavities, gaining energy each circuit, until they finally are prompted to collide with a fixed target or with a counter-circulating beam.



proton-antiproton machine, and proceeded, using van der Meer's innovation, to make the machine—and an almost equally innovative detector—work. According to Taubes' book, the fact that the machine *did* work elated Rubbia even more than the subsequent discovery of the W and Z particles.

SMASHING SUCCESS. So shocking to the United States was CERN's discovery that *The New York Times* editorialized on the need to recover the lead in particle physics. Physics advisers to the U.S. Department of Energy immediately recommended building a collider to end all colliders. At the same time, they decided to ditch a half-built accelerator at Brookhaven National Laboratory, on Long Island, N.Y., deeming it inadequate to plumb the ultimate mysteries of the standard model. Thus Brookhaven's Isabelle came to be known as "was-a-belle," and the ill-fated SSC project was born.

Meanwhile, the Europeans were not resting on their laurels. As early as 1978, when construction of a large electron-positron (LEP) synchrotron collider at CERN was being planned, the lab's leadership decided to make the LEP tunnel as big as possible—in both circumference and volume—so that it could be used for a second collider in the 1990s. In 1985 Rubbia was asked to head a committee on long-term planning, and in due course that committee recommended building a proton-proton supercollider in the 27-km LEP tunnel.

As competing plans for the U.S. and European colliders evolved in the late '80s, it is probable that most U.S. particle physicists regarded CERN's plans, if they noted them at all, with a certain disbelief. Why, if the United States was going ahead with a 40-TeV supercollider, would Europe bother to build a machine with less than half the energy for essentially the same purposes, according to much the same design, and on pretty much the same schedule?

CERN's leadership, in essence, made this case. Its collider (they said) would compensate for lower energy with higher "luminosity" (a measure of collision-event rates). The machine would have a much better than even chance of finding the Higgs bosons, despite its lower energy, and while the SSC would have been somewhat better equipped to find the Higgs, the LHC would have had a good chance of being finished before the SSC.

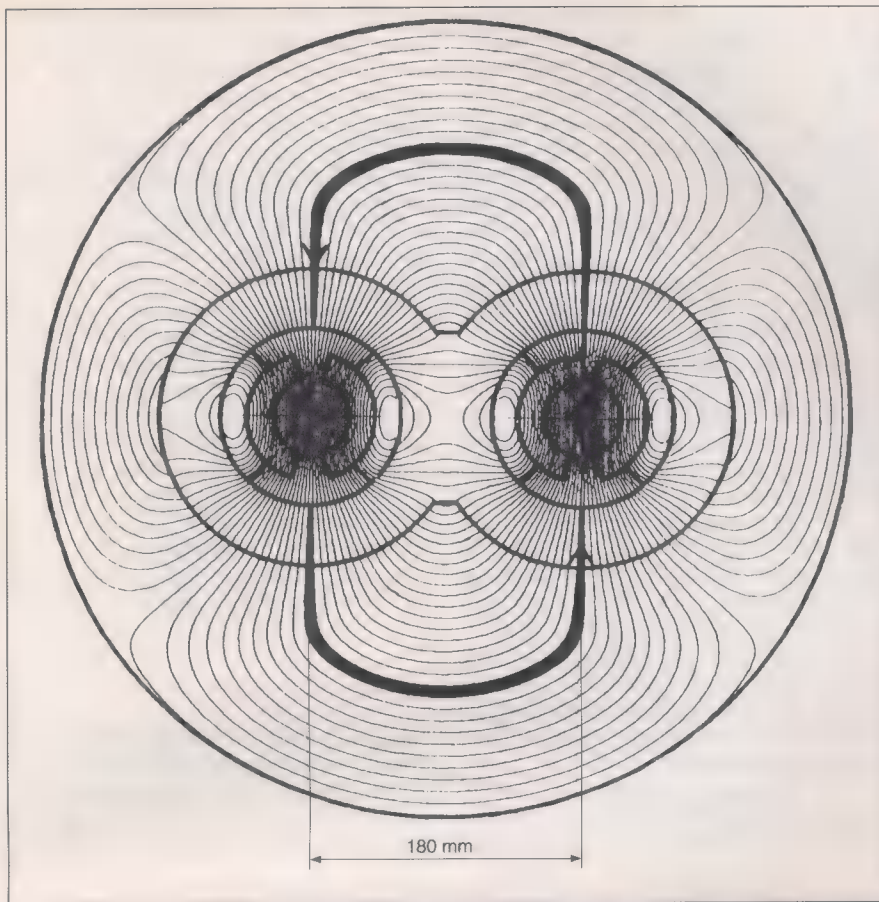
Even if the LHC failed to find the Higgs first, they argued, it still could do a lot of other good proton-proton physics—plus do double duty as a heavy-ion collider. Possibly, too, it could be used in conjunction with LEP as a proton-electron collider, not unlike a somewhat eccentric machine that was to start up in 1982 in Hamburg, Germany.

Moreover, CERN's leadership boasted that the LHC would be able to do all that at much lower cost than the SSC, because it

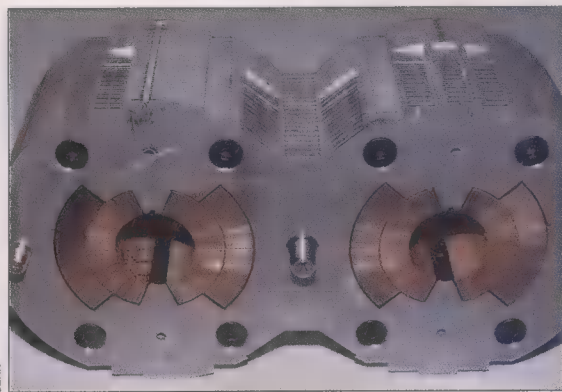
would build on existing resources at CERN rather than be constructed from scratch. As Christopher Llewellyn Smith, the current director general of CERN, put it in a recent article, "the value of existing facilities that will be incorporated in the LHC, namely, the Linac, Booster, Proton Synchrotron, Super Proton Synchrotron, LEP tunnel and LEP-II cryogenics, as well as site amenities such as buildings and roads, exceeds that of the new elements of the LHC, making the project very cost effective."

The total projected cost of the LHC, excluding detectors and CERN personnel, is currently estimated at about US \$2 billion, about twice the first, informal estimates made around 1987. Current plans call for holding the cost of each of two detectors to about 300 million Swiss francs (US \$230 million). The SSC, partly because it would have started from scratch, was last estimated to cost more than \$10 billion when it was canceled last year.

HOW IT WORKS. As Llewellyn Smith's statement implies, LHC will rely—like all the most advanced colliders currently operating or planned—on cascade acceleration. This technique uses a series of boosters and rings, each optimized for a specific energy range. Initial acceleration takes place in a proton booster and in the Low Energy Antiproton Ring (LEAR). Next the protons and antiprotons are fed into the existing Proton Synchrotron, then into the existing Super



The proposed two-in-one dipole magnets for the Large Hadron Collider will stretch superconducting magnet technology to the limit of the art. Made of niobium-titanium conductor material and cooled by superfluid helium, they will operate at 1.8 K. The field strength is to be 8.65 teslas, versus 4 T for the magnets at Fermilab's Tevatron and 6.6 T for those planned for the now defunct Superconducting Supercollider.



Proton Synchrotron, and finally into the main storage ring, where bunches of protons and antiprotons are made to collide.

At every stage, acceleration is effected by radio frequency cavities. As protons or antiprotons cross gaps between charged plates in a vacuum, they acquire the energy of the voltage difference between the plates. But the orbits of the circulating particles tend to get larger with increases in energy, and therefore have to be stabilized by increasing magnetic fields in synchronization.

Strong focusing of the beams, essential to achieving the collision rates needed and to the economics of any large ring, is accomplished by means of quadrupole magnets. Following the usual practice, these are sepa-

rate from the dipole magnets used to steer and bend the proton beams.

A fairly innovative feature of the LHC, however, is that both the quadrupole and dipole magnets will contain separate vacuum channels for the proton and antiproton beams, rather than having twin sets of magnets for each beam.

Like the Tevatron and planned SSC, the LHC will rely on superconducting magnets. It will draw on technology initially developed under Wilson's leadership at Fermilab and brought to fruition largely through contributions by Alvin Tollestrup, who worked there and at the California Institute of Technology at Pasadena. Tollestrup found ways of dealing with the eddy currents that tend to arise in such magnets,

"quenching" their superconductivity with the hot spots caused by micromovements of the superconducting material.

Pushing the state of the art

Will the LHC be able to escape further cost escalation of the kind that doomed the SSC? It has always been recognized that the LHC is much the riskier technically. Because the collider has to be placed in an existing tunnel on top of another accelerator, its size is sharply constrained, pushing the limits of detector and magnet technology.

The two detectors already have been selected. Their designs were to be finalized, in detail, before CERN went to the member states for authorization of the project. Complete finalization was deferred at the end of last year only because of international negotiations that were opened with U.S. physicists and other parties as a result of the SSC's demise.

Both detectors are general-purpose devices designed to cover the full range of relevant physics. The one called Atlas will consist of a large air-core superconducting toroid, surrounding an inner superconducting solenoid, coaxial with the beams. The other detector, called the Compact Muon Solenoid, consists of a single superconducting solenoid.

Atlas's toroidal coils will circumscribe a magnetic volume 26 meters long and 20 meters across. Along with the solenoid magnets, they will bend the tracks of most of the particles created in collisions, so that measurements of the particles' mass and momentum can be made. The solenoid's iron yoke and the hadron calorimeter inside it are designed to capture everything but muons, which are to be detected in the outer tracking chambers (the calorimeter measures the heat energy deposited by the various particles).

The basic idea, the experiment's spokesman Peter Jenni explained, is for the toroid and the solenoid to make measurements of electrons and muons completely independently, so that the two parts of the detector will not share systematic errors and thus can verify (or nullify) each other's results.

Atlas, Jenni claims, will be able to handle luminosities even higher than those called for in the machine's design— 10^{34} events per square centimeter per second, or one order of magnitude greater than what the SSC was designed for. In this context, an event is a collision of any kind between two particles.

The Compact Muon Solenoid is more compact than Atlas but, at 12 000 tons, twice as heavy. Tracking components are placed right up against the beam pipe, subjecting the elements to extraordinarily intense radiation.

Easily the toughest challenge associated with the detectors will be figuring out how to process and collect—in real time—the data from the LHC's enormously intense

collisions. With bunches of proton beams crossing each other 40 million times per second, and with up to 20 events occurring at each collision, the machine will yield almost 10^9 events per second.

The data will be hard to manage. Triggers built into the detection electronics will have to be able to select one event out of every hundred million or so to save. The idea will be to discard events encountered in the past and save novel ones, which by inference will be more interesting.

One obstacle to detection is the extreme brevity of the interval—roughly 25 nanoseconds—between crossings of bunches of proton beams. Being so closely spaced, interesting events, representing rare physics processes, will tend to pile on top of common and uninteresting events from the same bunch crossing. To minimize the problem, CERN engineers have chosen to use what are known as high-granularity detectors, with relatively large numbers of detector channels.

All the data from these detectors will be initially stored in pipeline memories, acting in effect like delay lines. The data from a small fraction of events of interest will be transferred to buffer memories away from the detectors. Only after a second-level sifting of this buffer data will the events of interest be fully reconstructed.

Big challenges also are associated with the unprecedented radiation levels and the heat that the detector components will endure, especially those in the Compact Muon Solenoid. "At peak luminosities," a CERN report on the LHC pointed out, "there will be about ten million charged particles per square centimeter per second at a radius of 30 cm from the interaction point.... The high-speed electronics attached to the trackers will generate some 20 kW of heat in a relatively small enclosed volume."

The challenges and risks connected with magnet development seem equally daunting. Field strengths of more than 8 teslas will subject the structures containing yokes and cryostats to enormous stresses, and state-of-the-art cryogenics will be required to produce these fields.

The key to obtaining such strong fields is the use of superfluid helium at 1.9 K, according to Lyndon Evans, who heads the LHC design team. The LHC's magnets will be filled with static helium, Evans explained, and superfluid helium, obtained by pumping the pressure down to about 1.6 kilopascals, will be trickled through heat exchangers alongside the magnets, yanking the temperature down to 1.8-1.9 K.

The lower temperature of superfluid helium, Evans said, buys about 3 T in field strength. It permits higher current densi-

ties and field strengths without loss of superconductivity. It also exploits the tremendous thermal conductivity of the liquid—about 10 000 times that of copper—to carry heat out. The LHC will be the first particle accelerator with magnets cooled by superfluid helium; Fermilab's Tevatron uses regular liquid helium at 4.2 K.

While CERN's leadership has expressed confidence all along that it will achieve magnet goals and recently won a vote of confidence from the lab's governing council, the magnet development program has not been completely without hitches. The lab managed to test some individual magnets successfully, but contrary to earlier plans, it was unable to test a string of magnets before going to its council for authorization of the LHC. And last year, it had to scale back the targeted magnet field strength to 8.65 T from 9.5 T. That translated into a reduction in the targeted center-of-mass (collision) energy to about 14 TeV from 16 TeV.

Finding the Higgs

The LHC's design energy of about 14 TeV will be required to achieve collision energies of around 1 TeV for quarks, the constituents of protons and neutrons, as well as for gluons, the particles mediating the

The mysterious universe of elementary particles

Current understanding of elementary particles is summed up in what physicists call the standard model. This model is built out of two kinds of particles and three basic types of forces: namely, force particles and matter particles, plus gravity, the strong force (which binds quarks together into protons and neutrons), and the electroweak force.

The photon, carrier of the electromagnetic force, is an example of a force particle, while the electron is a matter particle. The electromagnetic and weak components of the electroweak force were considered distinct until the 1970s, when high-energy experiments revealed their underlying symmetry and similarity.

This was one of the great experimental discoveries of the 1960s, '70s, and '80s, made largely at U.S. and European accelerator laboratories. They can be summarized by listing the force and matter particles observed then for the first time. The W and Z particles, for example, discovered in 1983, are the force particles for the weak interaction; they are particularly massive—80-90 times more so than the proton. They were found at CERN, the acronym by which the European Laboratory for Particle Physics is known.

Quarks, the main constituents of protons and neutrons, are particles with fractional charge: $+2/3$ or $-1/3$, if the charge of the electron is taken as -1 . The proton is basically composed of two $+2/3$ and one $-1/3$ quark, for a total charge of $+1$, and so on. The top quark, which researchers at Fermilab in Batavia, Ill., recently claimed to have found,

weighs 174 GeV—as much as the nucleus of a gold atom. So far three families of quarks have been found. Each has a pair of quarks and a corresponding pair of leptons, which are electron-like particles that interact with electromagnetic, gravitational, or weak forces.

The first real mystery about elementary particles concerns neutrinos. In the standard model, the neutrino is a partner to the charged lepton, otherwise known as the electron. There are three types of neutrinos, labeled by the lepton type—electron, muon, and tau. However, the electron is more than 50 000 times as massive as the electron neutrino, and there are hints from solar-neutrino experiments that the mass ratio could actually be more than a billion to one!

Why are the neutrinos so massless? No conservation law or other physical principle demands this. On the other hand, if one of the neutrinos were to have a mass of only 30 electron volts, then the mass of all the neutrinos in the universe (left over from the Big Bang) would far exceed that of all other matter (the matter in stars, humans, Buicks, and so on). This, in turn, could mean that the universe will eventually collapse in what British physicist Stephen Hawking has called the Big Crunch.

How can such tiny neutrino mass be measured? It is done by exploiting an interference effect, similar to that for light waves, called neutrino oscillations. Experiments along these lines are being set up in the United States and at CERN, and other experiments, in which I am participating, are

planned in which a neutrino beam will be shot from CERN to the Gran Sasso Laboratory, west of Rome.

This leads us to the second mystery of elementary particles: where does their mass come from? This question is deceptively grand, implying as it does a reference to the mass of all matter in the universe. In the standard model, mass derives largely from the force created by the exchange of a new particle called the Higgs boson (after the theory formulated by the Scottish physicist Peter Higgs). The discovery of this particle was the goal of the now canceled Superconducting Supercollider, and will be the main goal of the Large Hadron Collider (LHC) at CERN [see accompanying article].

What if data gathered at the LHC strongly suggest there is no Higgs boson? This is the nightmare that many theoretical physicists must sometimes have—because if no Higgs exists, their field is back to Square One. Of course, there could be a new world of particles waiting to be discovered at the LHC that could clarify this mystery.

The third great mystery of particle physics has to do with the violation of a sacred symmetry principle called time reversal invariance. Until 1964, it was assumed that the laws of physics were immutable with respect to the direction of time—that is, the laws were the same whether time ran forward or backward. However, in a famous experiment at Brookhaven National Laboratory, on Long Island, N.Y., Val Fitch, Jim Cronin, and their colleagues discovered a process that indicates that the laws of physics actually do depend on whether time is running forward or backward. This is, though, a tiny effect, and no one yet knows if it is intrinsically

strong force that binds the quarks inseparably together. Llewellyn Smith said that the 2-TeV reduction in design energy from 4 TeV due to reduced magnet field strengths will not prevent the machine from finding new particles such as the Higgs. The assertion is not disputed by competing labs.

What exactly is the Higgs and why is it so important? The first question is much trickier to answer than the second. Explaining what the Higgs is to the educated public has proved to be almost as hard as conceiving it and, possibly, finding it. Last year a newly appointed science minister in Britain, which happens to have been the wariest of the European countries in supporting the LHC, offered a bottle of champagne to the particle physicist who could best explain the Higgs in one single-spaced typewritten page.

At the back of the official's mind, no doubt, was an influential report that had appeared in Britain nearly 10 years before. In it, particle physics was declared *not* the most fundamental science imaginable and a reduction or slowdown in British support for particle physics was recommended. (Llewellyn Smith, then the British particle physics community's designated spokesman, called the report a "knee in the groin" in an interview with *Physics Today* magazine.)

The contest produced a five-way tie. In what was probably the most popular entry,

David J. Miller of University College, London, drew a political analogy. First, he explained the Higgs mechanism, by which the particles impart mass to quarks and to vector bosons (carriers of the weak force, which governs radioactive decay). He imagined an unnamed (but female) ex-prime minister crossing a room, so that as she passed, a moving cluster of people formed around her. "Because of the knot of people always clustered around her, she acquires a greater mass than normal, that is, she has more momentum for the same speed of movement across the room," Miller wrote.

Then, by way of explaining the Higgs particle itself, he conjured up a hot political rumor crossing the same room of political workers, so that clusters again form as it crosses. "Since the information is carried by clusters of people, and since it was clustering which gave extra mass to the ex-Prime Minister, then the rumor-carrying clusters also have mass," he explained.

Miller also pointed to an analogy in the physics of solids: "A crystal lattice can carry waves of clustering without needing an electron to move and attract the atoms. These waves can behave as if they are particles. They are called phonons, and they too are [mass-mediating] bosons."

In the entry the *CERN Courier*, the laboratory newsletter, chose to reprint, Simon

Hands of the CERN theory division described the Higgs field as endowing space with a "grain," like wood. He wrote: "Particles called vector bosons can travel with the grain, in which case they move easily over large distances and may be observed as photons—particles of light. Against the grain, particle ranges are much shorter—these are the W or Z particles.... When particles of matter such as electrons or quarks travel through the grain, they are constantly flipped 'head over heels.' This forces them to move more slowly than their natural speed, that of light, by making them heavy. Only the elusive neutrino seems (as far as we can tell) to spurn interaction with the Higgs and remain massless."

HIGGS EPIPHANY. Higgs bosons of several possible varieties could reveal themselves in a multitude of signatures, but two are considered most probable and most foolproof. The clearest evidence of a Higgs weighing less than 130 GeV would be a photon pair manifesting itself in a very narrow energy "window" of just a few gigaelectronvolts, and this is why super-sensitive measurement of particle energies features in both detector designs.

For the Compact Muon Solenoid, according to the collaboration's spokesman Michel Della Negra, the most effective, but most expensive, means of detecting photon pairs would be the photoelectric effect in a

small or just the iceberg-like tip of a large effect.

One approach to understanding the effect is to study it in relation to a quark in the third family, a particle known as the bottom (b) quark. Various so-called b factories using electron-positron collisions and proton collisions are being set up in Japan, the United States, and Europe.

Another way is to build a so-called σ factory, a very intense low-energy electron-positron collider that produces a multitude of correlated particles to be used to study symmetry principles. One is being built at Frascati, Italy, and another kind may possibly be built some day at the University of California at Los Angeles.

The fourth and perhaps greatest mystery of all contemplates the possibility of new scales of physics at vastly higher energy. For example, the theory of the Grand Unification of Forces postulates that the weak, electromagnetic, and strong forces are all united at the incredible energy of 10^{12} TeV—or 500 000 million times the level attainable in Fermilab's Tevatron, the highest-energy colliding-particle machine now in operation. If this is so, the real mystery may be why any low-energy things, like protons and electrons, exist at all! Furthermore, it would have enormous implications for one of the most exciting new fields of science called Astroparticle Physics, or Particle Cosmology—the study of the universe before it was even quadrillionths of a second old, when the only things that existed were elementary particles.

The grand unification theory is not without its own type of puzzle, which some say leads to the concept of the supersymmetric nature of matter. If

there is a new world of particles at the grand unification scale, they will interact, ever so feebly, with the low-energy particles that make up the world. In physics, such interactions will usually lead to the low-mass particles being "dragged up" to the high-energy scale.

But no one even knows for sure why there are any low-mass objects like the proton or electron in the universe. To date, only one explanation has been put forward: the theory of supersymmetry, which indicates a new particle for every existing particle. So far, not a single supersymmetric particle has been observed; but the LHC and the Compact Muon Solenoid detector being worked on at UCLA and elsewhere are being readied to observe these particles, if they do exist.

The only direct way to test whether there are such entirely new physics at extremely high energies is to discover the decay of the proton. The current belief is that the proton is not entirely stable but will decay through the mediation of a very high-mass, virtual particle. Such particles are postulated in the Grand Unification of Forces scheme and supersymmetric versions of these theories. Carlo Rubbia, I, and others are building a 5000-ton, ultrapure liquid-argon detector called Icarus at the Gran Sasso underground laboratory to continue the search for proton decay to the ultimate level possible on earth. We shall also be conducting many indirect experiments, including some on the origin of the dark matter in the universe.

The supersymmetric Grand Unification theory also provides for stable, neutral, lower-mass particles that would have been made in the early uni-

verse. These particles could make up some of the missing, or dark, matter in the universe. Experiments are in progress around the world to attempt to detect this supersymmetric dark matter using very sensitive detectors at underground laboratories.

Which brings us back to the first mystery: why the neutrino has so little mass compared to the Grand Unification scale, a full 28 orders of magnitude in energy, or mass, for the electron neutrino. The very fate of the universe as we know it may be revealed by these ratios. The Grand Unification energy scale set the early universe structure and perhaps a tiny neutrino mass will determine the long-term fate of the universe—from beginning to end!

All in all, since the great heyday of particle physics discoveries in the '70s and '80s, the field has matured. It is now treating the very fact and fabric of the universe as a laboratory for the future, while devising and building new accelerators and new principles of acceleration to push the energy envelope here on earth. No wonder physicists are so chauvinistic about their field!

—David B. Cline

David B. Cline is a professor in the departments of astronomy and physics at the University of California, in Los Angeles (UCLA), where he initiated and now directs the Center for Advanced Accelerators. An associate editor of the Nuclear Physics B journal, he includes among his research interests the development of an asymmetric σ factory at UCLA, the decay of the proton, and the search for neutrino mass using various methods.

crystal such as cerium fluoride or lead tungstenate. Also being evaluated is ■ hard glass, and the fallback option would consist of plastic scintillators in a shish kebab configuration. A similar option for Atlas calls for lead converter plates and liquid argon in an accordion configuration.

A Higgs weighing between 130 GeV and 1 TeV would show up most clearly in two pairs of leptons (electrons or muons). A muon is the collective name given to a pair of elementary particles with positive and negative charge, certain spin characteristics, and ■ mass of about 105.7 MeV. Since muons are highly penetrating and energetic, a strong magnetic field or long trajectory is needed for mass estimates, which explains the tradeoff between size and field strength in the alternative Atlas and Compact Muon Solenoid designs.

Finding the kind of simple Higgs called for in the current standard model of elementary particles and forces is of course not the only rationale for the LHC (nor was it for the SSC). Della Negra and many of his colleagues believe that the simple Higgs is "too simple." They consider up to five Higgs bosons more likely, as anticipated in supersymmetry, a theory that strives for unification of the electroweak and strong forces at the cost of pairing all the known particles with supersymmetric mates. Thus, every quark would be paired with a so-called squark, and the force-mediating gauge boson would have much heavier boson partners (such as the Z' or W').

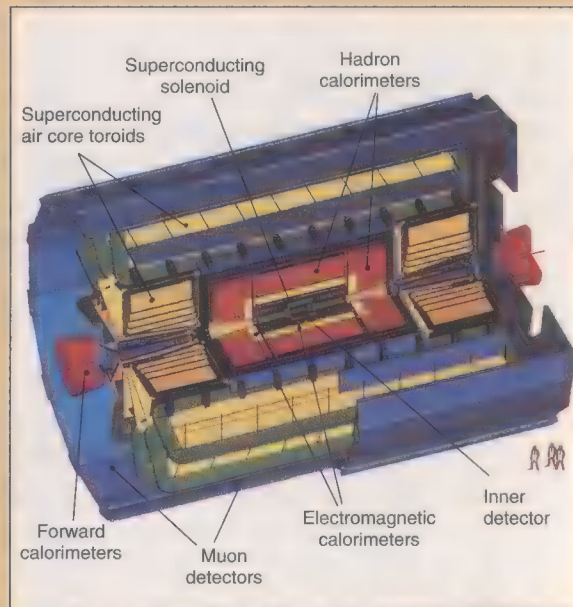
But it also is agreed that those much heavier-gauge bosons or supersymmetric gluinos would only appear at the very top of, and perhaps above, the LHC's energy range, and so Della Negra concedes that the SSC would have been a better instrument for finding them. Thus, the Higgs particle and the associated Higgs mechanism are the one phenomenon that the LHC seems certain to illuminate.

HELP WANTED. Last year, the experimental physicist and Nobel Laureate Leon Lederman published a book that he gave the provocative and perhaps impolitic title, *The God Particle*—in honor of the Higgs. He dubbed the Higgs "the God particle," he said, because is "so central to the state of physics today, so crucial to our final understanding of the structure of matter, yet so elusive."

Elaborating later in the same book, Lederman said: "The variation of mass with state of motion, the change of mass with system configuration, and the fact that some particles—the photon surely and the neutrinos possibly—have zero mass, all challenge the concept of mass as a *fundamental* state of matter."

In *Dreams of a Final Theory*, a book in a very different style, Steven Weinberg of the University of Texas wrote: "Out of the fusion of relativity with quantum mechanics there has evolved ■ new view of the world, one in which matter has lost its central role.

Atlas, one of the two detectors planned for the LHC, consists of a large toroid surrounding an inner solenoid. Muon measurements will be possible even outside the device's calorimeters, enabling it to handle event rates still higher than those called for in the current machine design. The Compact Muon Solenoid, the other detector, consists of a more compact solenoid, 15 meters long with an inner radius of 3 meters. Its superconducting coil is to achieve 4 T and will be the largest ever built. It will consist of three-component superconducting wire in four layers, each layer being formed of a niobium-titanium and copper composite, surrounded by a pure aluminum envelope (to stabilize the current in the event of quenches) and then an aluminum alloy (for structural integrity).



This role has been usurped by principles of symmetry, some of them hidden from view in the present state of the universe."

It was Weinberg, together with Abdus Salaam and Sheldon Glashow, who was primarily responsible for devising the electroweak theory and its elaboration as the standard model, based on principles of symmetry and symmetry breaking.

Weinberg, one of the best-known of physics Nobel Laureates, is not shy about saying why a supercollider should be built to find the Higgs: "The reason we give the impression we think that elementary particle physics is more fundamental than other branches of physics is because it is."

Ironically, the Weinberg and Lederman books, written in support of the SSC, have turned out to be arguments for the LHC and for 500 or so veterans of the two proposed SSC detector collaborations who now are seeking to participate in the LHC. At the end of last year, when CERN deferred finalizing the detector proposals, the objective was to allow for the possible inclusion of technical contributions from a wider circle and, it is hoped, more solid funding as well. CERN has made it plain that it expects a financial contribution of about \$500 million for the project from the United States—a departure from traditional rules requiring open international access to major physics facilities.

CERN's position is that the balance of exchanges in particle physics is now shifting so decisively to Europe, with many more U.S.-based particle physicists working on European machines than vice versa, that the laboratory cannot do without compensation from major nonmember partners. While CERN also has insisted all along that it will build the LHC no matter what, it has

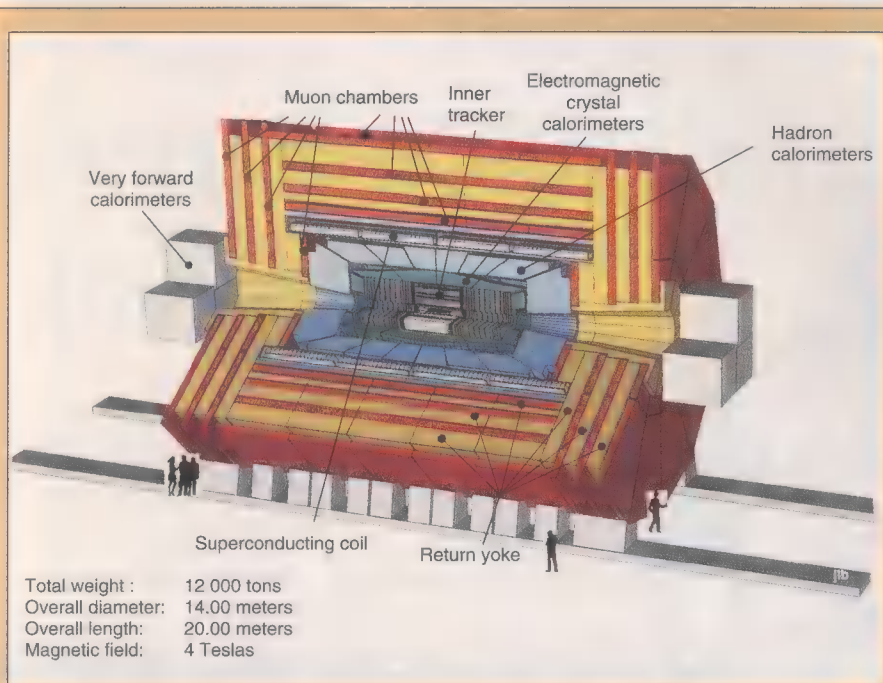
admitted its financial situation will be precarious without added outside support.

Atlas spokesman Jenni reports that his project has been joined by the spokesmen for the two SSC detector collaborations, William Willis of Columbia University and George Trilling of the University of California, Berkeley. His hope is that participation and funding by U.S. and other non-European groups will enable the Atlas team to go straight to the full detector design, rather than approach it in stages.

Della Negra, similarly, hopes that U.S. participation will enable the Compact Muon Solenoid to use one of the more optimal crystal detector designs. A total of 36 U.S. groups and 266 U.S.-based individuals have signed up to work on the detector, and they have submitted a letter of intent to the U.S. Department of Energy requesting R&D and construction funds. The U.S. teams have been given well-defined responsibilities for the Compact Muon Solenoid, namely development of the hadron calorimeter, which is to be centered at Fermilab, and development of the end-cap muon detection systems.

So far, the Clinton administration has emitted mixed signals as to whether it would underwrite the participation of U.S.-based physicists in the LHC. An advisory committee headed by Sidney Drell, deputy director of the Stanford Linear Accelerator Center, in California, has recommended it do so, and that recommendation has been endorsed by members of the House of Representatives' science committee.

But, in addition to the bruised feelings of the U.S. physics community, there are concrete competing interests to be taken into account. Just closing down the SSC is costing \$640 million this year and may cost \$180 mil-



lion more next year. In effect, the canceled supercollider still threatens other U.S. projects in particle physics, and U.S. funding for Europe's scheduled supercollider might threaten them still more.

Exciting times in physics

The design and construction of the LHC and its planned search for the Higgs boson are among the most vital and fascinating endeavors in particle physics. But these are interesting times in high-energy physics, for a number of other projects of fundamental importance are also planned or under way.

In the next few years, Fermilab's Tevatron is to have its two detectors upgraded for another decade of operation. Last spring, one of the Tevatron collaborations cautiously published what it called "evidence for the top quark," the sixth and presumably final quark. If the evidence holds, as is generally expected, this will be the lab's second major find—the first having been the discovery of the upion pi-meson by a team led by Lederman in 1977. This discovery, together with that of the tau particle by Martin Perl at the Stanford Linear Accelerator Center two years before, firmly established a third category of quark-lepton pairs.

Since the early 1970s it has been apparent that quarks and leptons exist in pairs, and that each quark pair corresponds to a lepton pair. The second of these quark-lepton pairs or families, and indeed the existence of quarks, had been firmly established by the discovery of the J/psi particle simultaneously by Burton Richter at the Stanford center and Sam Ting at Brookhaven in 1974. Quarks, it turns out, come in six different types, known as "flavors," with

names like bottom, strange, and charm. Thus the upion particle consists of a bottom quark and its antiparticle, and the J/psi of a charm and an anticharm quark.

Brookhaven's main project today is the Relativistic Heavy Ion Collider, built in the Isabelle tunnel to create and study the quark-gluon plasma—a condition expected to arise at about 10^{12} K. Such plasmas are a key to elucidating the complex interactions of quarks and gluons, and are created by slamming together heavy ions, such as those of uranium, in accelerators. Similar experiments are under way at CERN on the Super Proton Synchrotron, and the LHC will double as a heavy-ion collider with a quark-gluon experiment called Alice.

The major current project at the Stanford center is the Stanford Linear Collider, an electron collider that came on the air just after the first stage of LEP at CERN. LEP I, as this stage is known, has been a much more fertile producer of Z particles since it yielded its first in August 1989, and will be more fertile still after it is upgraded (to LEP II) with more than twice the energy—96 GeV from 45.5 GeV.

But the Stanford collider turns out to be much better fixed to do a kind of beam polarization experiment, permitting it to do superior estimates of the so-called Weinberg angle, named after the University of Texas' Steven Weinberg. This parameter, also known as the coupling constant, is a numerical prediction about the relative strengths of the strong and electroweak forces at the energy levels attainable in current experiments—and a cornerstone of the standard model. While LEP has been yielding Weinberg angle measurements, the Stanford collider's data generally are held

more reliable, and for the time being CERN is planning to leave the field to Stanford.

The Stanford Linear Accelerator Center and the KEK laboratory in Japan are both planning machines to produce copious numbers of B mesons. These so-called B factories should shed light on charge and parity violation—symmetries of mirror imagery and charge reversal—which may account for the dominance of matter over antimatter in the known universe.

The discovery of parity violation in the late '50s and its theoretical elucidation by Chinese-Americans T. D. Lee and C. N. (Frank) Yang, followed by the discovery of combined charge and parity violation in the early '60s by Val Fitch and James Cronin, created conundrums in existing particle theory. The findings paved the way for development of the standard model, based on fundamental symmetries or conservation laws.

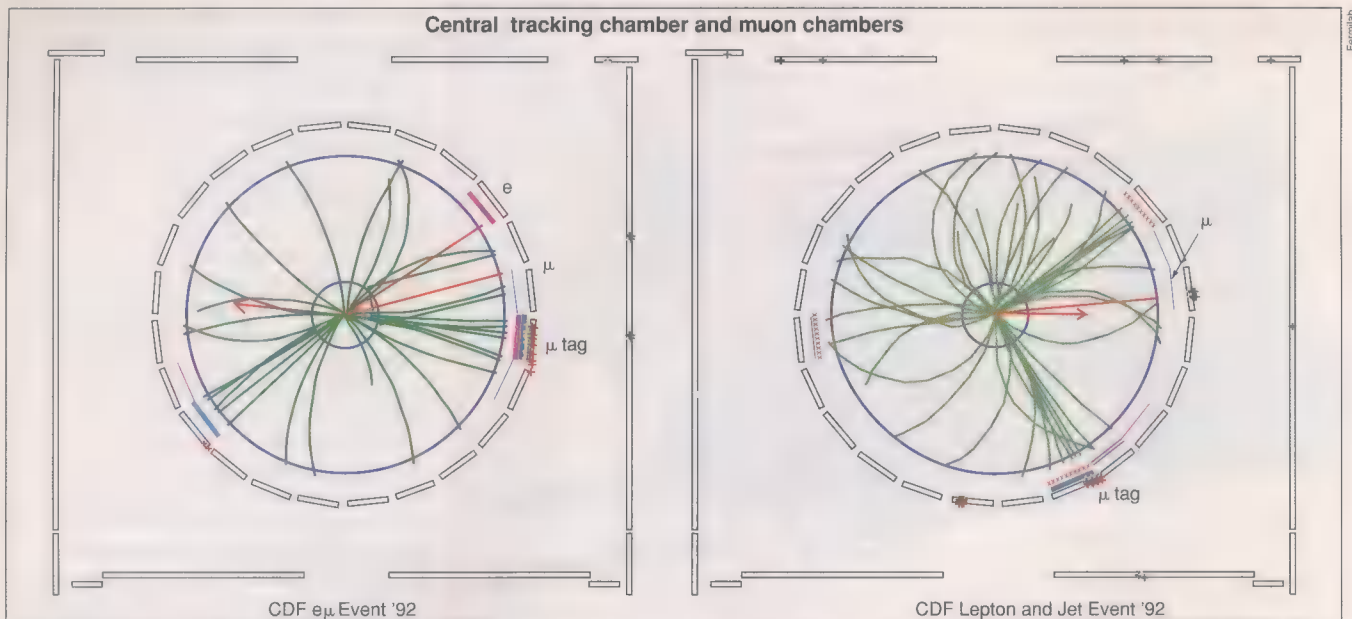
EYE OF THE BEHOLDER. One notoriously unsatisfactory aspect of the standard model is the arbitrariness of the masses the various particles prove to have. Another is that several key parameters have to be determined empirically. Since the parameters do not follow ineluctably from the theory itself, the theory lacks an aesthetic quality that Weinberg somewhat curiously names "rigidity"—not normally considered an attribute of beauty.

In a footnote to his recent book, *Dreams of a Final Theory*, Weinberg himself claims that the first Weinberg angle measurements from CERN constituted the first material evidence for supersymmetry, a theoretical construction outside the standard model. But Lorenzo Foa, CERN research director, disagrees with this interpretation. In an interview, Foa said that so far LEP has only produced results that are fully consistent with the standard model.

Foa did say, however, that CERN's Weinberg angle measurements implied a top quark of 177 GeV, which strongly supported Fermilab's hunch that it has indeed found the top at about 175 GeV. But "to believe that, you have to believe the standard model," said Bill Carithers, spokesman for the Collider Detector collaboration at Fermilab that detected the evidence. He evidently values the empirical data above the speculative argument.

To speculate further, the latest top quark and Weinberg angle measurements suggest to some that the Higgs might turn out to be relatively light and might even be found by LEP II. But Foa said that even so, the LHC would still be needed to tell whether the find was the Higgs or one of the several Higgs bosons called for by supersymmetry.

END OF PHYSICS? Perhaps the most disconcerting aspect of the current scene in elementary particle physics is the growing feeling that no matter how big one manages to build, it will still be impossible to get into the range where a grand theory uniting the electroweak and strong forces could be defin-



The existence of the elusive top quark is fundamental to current physical models. Happily, recent experimental results from the Collider Detector at Fermilab, one of two Tevatron detectors, strongly suggest it has been found. These plots of data, which show how particles are bent in the detector's magnetic field, providing the raw data for mass estimates, are from the tracking and muon chambers of the collider. They show the results of proton-antiproton collisions at a combined energy of nearly 2 trillion electron volts. Any experiment confirming the top quark's existence starts with the creation of both top and anti-top quarks, each of which would have a W boson as a decay product. Each W, in turn, most probably would decay into an electron and muon (the type of event shown at left) or a lepton and a quark jet (at right).

itively confirmed and detailed. Because of basic physics constraints, CERN's LEP is the largest circular electron-positron collider that will ever be built, and while one more huge linear collider may be constructed early in the next century as an international project, it will almost certainly be the last of its kind.

The SSC would have been, essentially, the largest proton-proton collider that could be built, and even it would not have resolved all the questions that already have appeared on the horizon of particle theory. Thus, for example, a Higgs-like particle to play the symmetry-breaking role in a unification of the electroweak and strong forces would be beyond the reach of any imaginable accelerator.

"The inexorable progress of physics from the world we can see and touch into a world made accessible only by large and expensive experimental equipment, and on into a world illumined by the intellect alone, is a genuine cause for alarm," wrote physics journalist David Lindley in his *The End of Physics*. "What is the use of a theory that looks attractive but contains no additional powers of prediction and makes no statements that can be tested? Does physics then become a branch of aesthetics?"

And if it necessarily does, one might add, who will be the arbiter of taste? Will it be someone like the erudite and meticulous Weinberg, or an earthy, shoot-from-the-hip Lederman?

One of the more eccentric non-standard theories hypothesizes that quarks might themselves be made up of other particles. The possibility is being investigated by a

unique machine, a proton-electron collider, at the HERA laboratory in Hamburg. Admittedly, it is unlikely that HERA will find evidence for the "leptoquarks" postulated as the ingredients of quarks, and for associated force-mediating X and Y particles. But should it succeed, CERN would be in a position to use the LHC in conjunction with LEP—which LHC will sit on top of—as a similar but larger proton-electron collider.

Evidence for leptoquarks would, of course, be sensational—and a thrilling win on a long-shot bet. Foa said CERN would pull out all the stops with the LHC to follow up on such a discovery.

By the same token, Foa said, if the discrepancies between the Stanford collider and LEP measurements for the Weinberg angle should increase rather than diminish, then CERN would consider delaying LEP II and rebuilding LEP I to do beam polarization experiments like the Stanford center's.

Europe's long-term strategy of concentrating resources at a single major laboratory is evidently paying off. CERN now presides over the world's largest and most diverse set of accelerators, which it could reconfigure to take advantage of whatever exciting things are in store. Because of this flexibility and because of Europe's careful consultative decision-making, which results in treaty-like agreements in big science, it is overwhelmingly likely that the LHC will be completed as planned.

The icing on the cake, assuredly, would be evidence from the LHC of new physics beyond the standard mode, pointing the way to some grand unified theory.

But it will be quite enough if the machine proves that the standard model accounts satisfactorily for mass and thereby elucidates what has been, since Newton, one of the most fundamental and yet mysterious and elusive concepts in physics.

TO PROBE FURTHER. Europe's Large Hadron Collider is described in detail in "The Next Step," a booklet published by CERN, November 1993; it can be obtained from the Communication and Public Education Group, CERN, 1211 Geneva 23, Switzerland.

For a description of the Stanford and CERN electron-positron colliders, see John R. Rees, "The Stanford Linear Collider," *Scientific American*, October 1989, pp. 58-65 and Bertram M. Schwarzschild, "LEP, the World's Biggest Accelerator, is on the Air," *Physics Today*, October 1989, pp. 17-20. For Fermilab's proton-antiproton accelerator, see Leon M. Lederman, "The Tevatron," *Scientific American*, March 1991, pp. 48-55.

Three recent books deal with the quest for an ultimate "theory of everything": Leon Lederman (with Dick Teresi), *The God Particle* (Houghton-Mifflin, 1993); Steven Weinberg, *Dreams of a Final Theory* (Random House, 1993); and David Lindley, *The End of Physics* (Basic Books, 1993).

Some noteworthy magazine articles on future directions in particle physics include: Frank Wilczek, "10¹² Degrees in the Shade," *The Sciences*, January-February 1994, pp. 22-30; "Le LHC et l'Avenir de la Physique des Particules," *La Recherche*, September 1993, pp. 1018-1020; and Roger Cashmore and Christine Sutton, "The Origin of Mass," *New Scientist*, April 1992, pp. 35-39. ♦

Defense acquisition: grab the ax

The Department of Defense's acquisition system is 'broke' and fixing it requires the involvement of all concerned

T

he acquisition system used by the U.S. Department of Defense (DOD) is in bad shape. Consider the following true stories:

- One company's response to a Request For Proposal (RFP) on a modest develop-

ment program was literally too heavy—the number of copies required weighed 1800 kg—for the corporate jet to handle; instead, a Boeing 737 had to be leased at a cost of US \$25 000 to fly the material hundreds of kilometers to the program office. Only some 10 percent of the pages dealt with the hardware and software required to meet the program's performance specifications and with manufacturing the item. About 90 percent covered the "ilities"—reliability, maintainability, and so forth—and the required cost data.

- At the first review of a small engineering development program, Government representatives outnumbered contractor personnel by 20 percent. Only a few of the Government people could deal with the technical issues. Most were "ilities" types who wanted to discuss such matters as the logistics support plan for a training device that had yet to be defined.

- Over a five-year period, the workload of a certain company declined by 50 percent. During that time, the number of cars in the employees' and visitors' parking lots also declined by 50 percent. But the Government parking lot remained full.

- The program manager of a high-risk development program once announced with pride that 1000 people were working on his COEA (cost and operational effectiveness analysis), which, when completed, would have as many pages as five Manhattan telephone directories. This program was

Charles A. Fowler C.A. Fowler Associates

subsequently canceled because both of its challenging new features turned out to be problematical.

- The U.S. Secretary of Defense visited a major aircraft engine manufacturer whose workload was half defense and half commercial. He found 400 Department of Defense inspectors, but no inspectors for the commercial engine work.

- Several teams working for major contractors spent three years preparing to bid on a large DOD project. One hour before the deadline for the huge proposals, the Government informed the contractors that it had no further interest in the project, and refused to look at the materials they had prepared.

FOWLER'S APHORISM. I could present another 30 such anecdotes, and anyone with experience in defense acquisition could add 20 vignettes. What I call Fowler's aphorism holds that 30 consistent anecdotes plus 20

vignettes equal one hard fact. And that hard fact is this: the DOD acquisition system is "broke."

The good news is that no pair of Government servants is more aware of the problems or more competent to fix them than U.S. Secretary of Defense William J. Perry and Deputy Secretary of Defense John Deutch. For years now, they have both been expressing their concerns and calling for action. In office, they have assigned the highest priority to the task of reform, launching large-scale efforts to promote a more rational approach to development; to eliminate superfluous regulations, specifications, and documentation; and to work with Congress for legislative relief. Such reforms will ultimately benefit everyone from taxpayers to foot soldiers.

The not-so-good news is that a transformation of this magnitude, especially in the Federal government, cannot be accomplished



Illustrations: Robert Neubacker

solely from the top. Many entrenched bureaucracies depend for their very existence upon the failure of reform. Active, substantial support from the military services, DOD agencies, the Congress, contractors, the mass media, and the public will be needed.

The primary purpose of this article is to promote such grass roots support for acquisition reform by reminding those in "the system" and informing those not in "the system" of the seriousness of the problem. Some suggestions for DOD actions are also included.

WHAT'S WRONG? The problem starts with a so-called "requirements" process that ignores cost constraints and promotes overspecification and an overly rigid approach to development. Then there is a bloated and grossly inefficient procurement system whose bureaucracy has grown steadily over the past several decades (as it has in most Government departments, according to Vice President Al Gore).

How did this state of affairs arise? Basically because each defense acquisition problem that has cropped up over the years has in effect inspired the DOD or the Congress to add yet another obstacle, another set of unneeded peripheral tasks, or another layer of checks, meetings, and reports.

In the long run, each intended improvement has only made things worse. Many of us "helped." Whoever said "today's problems were yesterday's solutions" had it right.

For example, when some of us contractors delivered equipment before all the bugs had been eliminated, the DOD rightly demanded greater reliability, and the Reliability/Maintainability/Availability cult was born. When it became clear that contractors often had little incentive to save on costs, the Value Engineering cult was born. When certain systems were fielded without adequate testing, more thorough and objective tests were properly demanded; the result, in the fullness of time, was the Operational Test and Evaluation swamp. And so it has gone with Safety Engineering, Life Cycle Costs, Integrated Logistics, and so on.

Americans are like that. Whenever an opportunity presents itself, they develop programs and form organizations. With time, the original purpose dims, and the activity becomes an end unto itself. Most of these programs and organizations do some useful and even important work. But the cost of doing business in this way has become too high.

And then there are cost data required by the DOD. Formerly sensible requirements for detailed cost estimates for development and production have run riot,

to such an extent that bidders must now break them down in excruciatingly fine detail, even when a design is far from clear. These meaningless numbers, requiring large staffs to generate, must next be "validated" by some officer of the bidder, who anoints them as "truthful."

Then they are pored over, and challenged, by a horde of DOD auditors looking for inconsistencies. After all this, and some "normalization" of competing bids, each bidder is asked to submit a Best And Final Offer (BAFO).

In an article 15 years ago, I wrote of the BAFO process: "Now comes the time when



grown men gather in a room and spend their time, not trying to decide on what the cost would really be, but trying to guess what the grown men in the other rooms are going to do."

Sometimes an ambitious program manager or contracting officer will decide to go through the BAFO process more than once, ending up with a request for a Best and Really Final Offer (BARFO!). After all these shenanigans, the bidder's officer must again certify the truthfulness of the numbers.

PROLIFERATION. As the cults and their requirements—meetings, reports, data, more data, more meetings, more reports—have proliferated, so have the numbers of Defense Plant Representative Office folks,

known affectionately as DPROs: inspectors, auditors, security people, and the like. In fact, the expenses associated with these efforts exceed even those generated by the "ilities."

The Defense Science Board's Task Force on Defense Acquisition Reform, under Bob Hermann, senior vice president for science and technology at United Technologies Corp., Hartford, Conn., has noted that estimates of the number of DOD people laboring in the DOD acquisition system range from 100 000 to 500 000. With salary and benefits worth about \$100 000 each, these men and women cost U.S. taxpayers some \$10 billion to \$50 billion a year.

The task force concluded that in addition to cutting the bill for DOD personnel by \$4 billion a year, it would be possible to achieve "significant dollar savings from similar contractor personnel reductions." (Some believe the savings could be much greater.)

And this does not count the personnel at Federally funded research and development centers and at professional service companies. They, in fact, carry out most of the work for the DOD System Program Offices (SPOs), because the 100-plus people in each SPO are largely occupied with giving briefings and responding to other requests, especially from Congress.

AUDITS AND INQUIRIES GALORE. According to former U.S. Secretary of Defense Dick Cheney, "Every working day entails on average almost three General Accounting Office [GAO] audits of DOD; an estimated 450 written inquiries and over 2500 telephone inquiries from Capitol Hill; and nearly three separate reports to Congress, each averaging over 1000 manhours in preparation and approximately \$50 000 in cost. In addition, senior DOD officials spend upwards of 40 hours preparing for the six appearances as

witnesses and the 14 hours of testimony that they provide on average for each day Congress is in session."

Note that "Congress" usually means people on its staff—26 000 strong—who generate almost all requests for information; members of Congress have little knowledge or interest in them.

Some years ago Bob Everett, then president of Mitre Corp., Bedford, Mass., found a chart plotting the cost per pound of a number of missile types against their annual production rates. A curve had been fitted to the data. With his usual insight Everett noted that if you multiplied the cost per pound (the ordinate value) by the quantity being procured (the abscissa value), the

result was almost constant over the range of quantities normally purchased. To exaggerate only a bit, according to this curve, "The XYZ missile program will cost \$100 million this year; we can have 10 missiles at \$10 million each or 50 missiles at \$2 million, or 100 missiles at \$1 million each."

In other words, given the rates at which the DOD buys missiles, and almost everything else, procurement costs are completely dominated by overhead. In a March 1981 letter to Norman R. Augustine, chairman and chief executive officer of Martin Marietta Corp., Bethesda, Md., and then chairman of the Defense Science Board, Mitre's Everett and I suggested that only about 10 percent of the acquisition budget is spent on the "touch labor" involved in building systems and components. High overhead was bad enough when budgets also were high and items were purchased in at least modest quantities. With today's and tomorrow's reduced budgets, the system is lethal.

All military leaders spend time worrying about the "tooth-to-tail" ratio, or how much of the force at their disposal is the fighting component compared with the support component. Several years ago I fretted that if the DOD and Congress didn't handle budget cuts by "having at" the overhead, we would be worrying about the "gums-to-tail" ratio. Since nothing happened, I am now worried that the "tooth-plus-tail-to-overhead" ratio will go to epsilon in the foreseeable future.

To become competitive, much of U.S. industry has been forced to tighten its belt, to eliminate marginally useful operations and functions, and to cut overhead. Until quite recently, however, nothing of the sort happened at the DOD. Now, budget reductions are beginning to force a change. Every knowledgeable person knows that the system must be transformed. The challenge is how to do it.

GOING HOME. To start with, we must return to a system in which development is carried out in a reasonably informal manner, without the big SPOs and the auditors, inspectors, and peripheral "ilities" items. It must again be possible to try out small numbers of brassboards and prototypes, operated by the people who would really use them.

In fact, that more practical system was never completely abandoned: the United States has used it extensively in every war it has fought in modern times, including, as few may be aware, Operation Desert Storm. Nor has this approach lacked advocates: the Defense Science Board (DSB), using the

term "fieldable brassboards/prototypes," advocated its use in a 1990 Summer Study.

Both "brassboards" and "prototypes" were included to indicate the wide spread in formality and maturity of the devices that might be tested in this way. The idea is to learn quickly if a new device is useful with or without modification, or not at all—and to give users a chance of participating in the development of the device and of devising new tactics made possible by it.

NO TANKS, PLEASE. This simple, practical approach is the right way to establish requirements for new systems. Today's requirements process assumes that we know in great detail what is needed from a device. But real requirements have always followed technical advances.

My first boss, the late Luis Alvarez



(Nobel laureate and inventor *extraordinaire*) liked to point out that there was no military requirement for an atomic bomb. Hanson Baldwin, the military specialist of *The New York Times*, wrote some years ago that the "machine gun and the tank would still remain blueprint dreams if their development had awaited the specification of clear-cut military requirements."

In a discussion a few years ago, a young U.S. Army officer said, with a twinkle in his eye, "It is true that the Army wasn't interested in the battle tank [as World War I began]. However, we salivated at the very thought of a high-tech stallion!"

The fieldable brassboard/prototype approach is also the best way of reacting to new threats and opportunities. It has a further advantage: if a crisis arises, equipment can be pressed into combat use. Often, small quantities of a really new device can have a big impact. The dropping of the atomic bomb at the end of World War II is the prime illustration of the potentially vast impact of "brassboards" fielded in small quantities.

Most of the air-defense radar systems the British used during World War II were "brassboardy." In the Gulf War, two prototype JStars (Joint Surveillance and Target Acquisition Radar System) aircraft, with a number of ground stations rushed to the theater of war, made it possible to display enemy movements over a wide area.

During the same conflict, the GBU-28 bunker-busting munition was developed, deployed, and successfully used. Some 30 were built: two for test and 28 for theater use. Under normal procedures, 28 would have been allocated for test and, maybe, two for the user.

Many other fieldable brassboard/prototypes were made use of during the Gulf struggle—everything from computer-based planning systems to missile "fixes," special jammers, and identify-friend-or-foe *appliqués*. The whole communications,

command, and control (C³) and intelligence distribution system was improvised for the occasion. More than 4000 contractor personnel and many Government lab people were rushed to the Persian Gulf area, and many more remained in the United States devising hardware and software fixes and improvements not only for new systems, but for old ones, as well.

The same kind of technical support materialized during World War II, Korea, and Vietnam. This coupling of the technical community and the users is extremely important in developing weaponry for a modern

force, especially with the continual introduction of new capabilities, which open up the possibility of new tactics. As we have seen, the United States, to its great benefit, has always managed to arrange for such co-operation during wars and crises; some way should be found of arranging for it in peacetime, too.

BRASSBOARDS ON TARGET. My first recommendation is that the DOD institutionalize the fieldable brassboard/prototype approach as the standard for most development projects. Some areas should be permanently assigned to this approach, for example, air/ground battle management systems and most C³ systems, systems unique to a region, and systems whose utility is likely to be ephemeral, such as artillery fuse jammers.

This approach to R&D makes sense under any circumstances. But with today's greatly reduced budgets, it is essential.

Larry Lynn, deputy under secretary for advanced technology, has initiated this approach with his Advanced Technology Concepts Demonstrations, a thrust that

should be supported and expanded by the armed services and the Congress.

My second recommendation is that the DOD institutionalize close interaction between the technical and operational communities. Such interaction will come about naturally if the fieldable brassboard/prototype approach prevails, but must be expanded to include a technical cadre at each major military command.

NOT GOOD FOR EVERYTHING. The fieldable brassboard/prototype approach doesn't work for everything. Some brassboards and prototypes will be needed in quantity and must therefore be built through a more formal acquisition process. As a result, that process will also have to be restructured drastically to make it more efficient and responsive.

For this reason, a "commercial" model of acquisitions has been adopted by Deutch and Perry, with the able assistance of Noel Longuemare, principal deputy under secretary for acquisition and technology, and by Colleen Preston, deputy under secretary for acquisition reform. By stripping away the accumulated claptrap, the commercial model should achieve the desired efficiencies.

To date, these efforts have focused on describing the new approach, determining what new laws and regulations might be needed, and working with Congress and others to effect these changes. The DSB Acquisition Reform Task Force has completed the first phase of its effort and is now working to define the steps that will be needed for implementation. Since the transformation will take a good deal of time, a parallel effort is under way to make early changes to the present system.

These interim improvements are important. Past experience tells us that they will not come easily, for the system has an unbroken record of success in resisting and outlasting attempts at change, and its capacity for resistance is still strong. Negotiation has never worked. Arbitrary, dictatorial actions are necessary because the specifications, rules, and procedures surrounding each peripheral area are so complex that the people who have the authority and desire to take action do not have the time to understand them in sufficient detail to downsize them. Thus, there comes a time when the only practical approach is to take the meat ax and swing.

If such bold moves are not made, the pe-

ripheral and support groups will be the last to thin out. For example, a March 2 *Washington Times* story on defense cuts said "the vast majority of local Defense Department purchases—63.7 percent—are for goods and services that are used for headquarters operations and are not

ments, and their specifications—be removed from DOD RFPs. The SPOs should be given three months to negotiate this stuff out of ongoing contracts. The groups that write such specs must be abolished, too.

Back in 1970, the then-Deputy Secretary of Defense David Packard pointed out that

if you didn't abolish the writers, the specs would quickly return in another form. Packard went on to draft a sweeping order eliminating many "ilities" specs and abolishing the groups that wrote them. He sent a draft to the military services for comment.

The services asked him not to sign it because it would create chaos for existing contracts. They did, however, assure him that they understood what he was trying to achieve, that they agreed with his goals, and that future contracts would reflect his views.

Packard reluctantly—and, with hindsight, unwisely—agreed to these requests. Meanwhile, the services marched on down the primrose path. Thus ended the only real assault to date on the continuing growth of the peripherals.

PAIN AND SUFFERING. Eliminating the peripheral items will cause a lot of pain and create temporary confusion in a number of contracts. But smart Government and contractor people will figure out how to incorporate the truly necessary parts of the current system and to keep the really key people. The savings will be more than adequate to cover some inefficiencies produced by the period of confusion.

Also, DOD should rely much more on their contractors for maintenance, training, and logistics support. This approach could result in significant cost savings, as well as help preserve the defense industrial base.

In any case, firm and rapid action is the only way to escape our current predicament. As with smoking, the only sure way to stop is to go cold turkey. This leads to the fifth recommendation: reduce

the size of the SPOs and their support contractors could be cut by a factor of at least five, since most of these folks deal with the peripherals.

Remember that the defense acquisition system has been structured to achieve the impossible: the elimination of risk. Layers of procedures must be followed, checked by other groups, then rechecked by still others. In most cases, the SPO director lacks control over what happens but avoids criticism by following all the rules.

The assault is on

What may prove to be the most successful assault ever on the overblown military procurement system and its entrenched bureaucracies was launched three months ago by Secretary of Defense William J. Perry. His aim: to meet U.S. defense needs at a lower cost.

On June 29, Perry directed the U.S. armed forces to acquire as many systems and components as possible from the commercial market and to use "performance and commercial specifications and standards in lieu of military specifications and standards."

Military specs and standards will be authorized only "as a last resort" after special waivers have been approved. His emphasis is on product (performance) versus process (how to achieve it).

The kind of performance spec Perry wants might, for example, require an aircraft to fly at Mach 2.1 instead of describing the way it is to be designed and built. Perry also directed the under secretary of defense for acquisition and technology to change within 60 days the language of defense-acquisition regulations so that it encourages contractors "to propose non-Government standards and industry-wide practices that meet the intent" of military specs and standards. For new contracts valued at US \$100 000 or more, and for old contracts of \$500 000 or more that are still far from completion, these revisions were to become effective 120 days after the directive was issued.

According to Perry, the specs and standards listed in Defense Department Instruction 5000.2—the official guide for developing new systems—are no longer mandatory for program managers. Likewise, management and manufacturing specs and standards are to be "for guidance only." In fact, the under secretary of defense was told to "develop a plan for canceling these specifications and standards"—or, as a last resort only, "justifying their retention."

Perry also directed the secretaries of the armed forces and the directors of defense agencies to begin similar efforts of their own—many had already done so—and to write specs stating the results desired rather than the means of achieving them. In addition, Perry encouraged the DOD to join with industry associations to develop replacements for military standards.

He also called for "cultural changes" in the way program managers and acquisition decision makers go about performing their jobs. For example, he asked them, "at all levels," to challenge the requirements for systems, because the problem "of unique military systems does not begin with standards. The problem is rooted in the requirements-determination phase of the acquisition cycle."

—Alfred Rosenblatt, *Managing Editor*

highly vulnerable to cutbacks."

So my third recommendation is to outlaw BAFO. To steal a phrase from Mitre's Everett, the Government should "shoot or otherwise dispose of" any program manager or contracting officer calling for a BAFO. Anyone calling for a BARFO should be caned on national television and then executed.

The fourth recommendation is that the peripheral items—the "ilities," the detailed cost data, the extensive oversight require-

By distributing authority over many groups, responsibility is also diffused.

Further, the elaborate nature of the current process almost ensures that SPO directors will have gone on to other jobs before real problems created on their watch show up.

And who can blame the SPOs for being cautious when the DOD's inspector general, the GAO, the mass media, and losing contractors are all waiting in the wings to criticize or even to prosecute?

RELIABILITY TO ORDER. Everyone is rightly concerned about unreliable equipment. It is important to address this issue in some detail, for the armed forces must certainly have reliable equipment.

To start with, there is little if any correlation between the "calculated reliability" of any given piece of hardware and its failures in operation.

Some years ago, John Allen, then a department head at the Massachusetts Institute of Technology's Lincoln Laboratories, Bedford, Mass., noted that from 1959 to 1970 the mean time between failure (MTBF) specified for a series of 10 tactical airborne radar systems increased steadily from 10 hours to 250 hours. For each system, the contractor's reliability team submitted a detailed analysis using approved techniques and data from the failure-rate handbook. Every analysis showed that the design would achieve the specified MTBF.

There were many meetings with the SPO reliability teams, and many reports were submitted, criticized, and reworked extensively. But for each new radar, the MTBF actually achieved in operation was the same—about 5 hours.

This is a common story. Failure of military equipment, at bottom, is not a statistical phenomenon. It results from design problems—marginally stable circuits, uneven cooling causing hot spots, high-voltage transients that zap tender diodes, immature software, and so on—and occasionally from bad parts or poor workmanship. I have not seen a single case where a failure that occurred in a Reliability Test Demonstration was even in the reliability calculation.

These days, as numerous space systems demonstrate, electronic equipment (and many other kinds of gear) with stable, solid design and good parts and workmanship will essentially run forever. Official reliability activity contributes little to real reliability. The DOD can and should insist on solid design and on good parts and good workmanship without imposing a large "ilities" overhead.

PROBLEMS ELSEWHERE. Why have these peripherals grown so without challenge? The answer is that the system of checks and balances seems not to work in some areas.

For example, the Environmental Protection Agency operates largely unchecked at a huge cost to the nation. *Science* magazine, in a series of editorials, has pointed out

many cases of extreme overspecification and resulting exorbitant costs. For instance, the Safe Drinking Water Act (passed in 1974 and amended most recently in 1986) requires cities "to monitor at least 133 separate pollutants." One of them is a pesticide that "was used only on pineapples in Hawaii and has been banned for 15 years"; another is the "regulation of atrazine in drinking water [which] would cost \$93 billion per life prolonged."

On a smaller scale, but equally alarming, the Connecticut River Atlantic Salmon Restoration Project, which cost over \$600 million through 1991, has resulted in the return of 2720 adult salmon for an average cost per salmon of \$220 000. Disregarding the sunk costs, the ongoing annual cost per salmon [to operate the program] is about \$75 000 and is not improving.

Such abuses occur because it is risky, almost un-American, to attack anything so wholesome as reliability, value engineering, cost data, thorough auditing, a clean environment, and the like. Members of Congress, the GAO, and the DOD inspector general know that they could not get the right kind of headlines by seeking efficiency in these areas. Stories attacking these forms of waste have not sold newspapers, attracted TV viewers, or won promotions or prizes.

With enough attention and spotlighting, though, that might change. Maybe a small miracle will take place and the management of the DOD will get some help, and not just criticism, from the outside. A series in *The New York Times* or *The Washington Post*, a "60 Minutes" item, a long article in *The New Yorker*, and an objective Government Accounting Office review (now there's an oxymoron for you!) are urgently needed.

HAPPY DAYS. The DOD used to operate with small, compact SPOs capable of taking responsibility for their programs. Those days can return. The U-2 and SR-71 high-altitude spy aircraft and, more recently, the F-117A Stealth aircraft programs showed how to do it. The F-117A, for example, had a total of six engineers in its SPO, one for each discipline.

Drastic improvements in the acquisition system are the DOD's most important need. With them, the United States could have a capable high-technology force in spite of the reduced budgets available. Without them, an ever-increasing part of the budget will be spent on "overhead."

The job cannot be accomplished solely from the top down. Secretaries Perry and Deutch, distracted by transient crises, will have only limited time to spare for acquisition reform—even though, in the long run, it is the single most important defense issue before them. As Leonard Sullivan, a former assistant secretary of defense, observed some years ago, "In the Government, one is so busy working on the

urgent, there is no time for the important."

The military services, the contractors, and, with enough pressure, even Congress, the media, and the public must support Perry and Deutch in their efforts to make defense procurement rational. For this is truly, to use today's vernacular, a "killer issue."

TO PROBE FURTHER. For an early discussion of the Best And Final Offer (BAFO) procedures, see "Comments on the cost and performance of military systems," by Charles A. Fowler, *IEEE Transactions on Aerospace and Electronics Systems*, January 1979, pp. 2-10.

The Defense Science Board Task Force on Defense Acquisition Reform issued a report, "Defense Acquisition Reform," in July 1993. The board also recommended an acquisition approach based on fieldable brassboards/prototypes in its 1990 Summer Study report, "A Research and Development Strategy for the 1990s."

Earlier this year, "Blueprint for Change" (Order No. ADA 78102), a Department of Defense report on procurement practices, became available from the National Technical Information Service, U.S. Department of Commerce, Sales Department, Springfield, VA 22161; 703-487-4650. The price is \$44.50, plus \$4 handling.

A discussion of the time devoted by the DOD on responding to congressional requests appears in "Defense Management Report to the President," by Dick Cheney, then Secretary of Defense, July 1989, p. 27. The "commercial" model of acquisitions is outlined in Secretary of Defense William J. Perry's paper (February 1994), "Acquisition Reform—A Mandate for Change."

For a discussion of mean time between failure (MTBF) for tactical airborne radar, read the "Report to the DDR&E [Department of Defense Research and Engineering] on Tactical Radar," prepared by John Allen et al. for the Massachusetts Institute of Technology's Lincoln Laboratory, May 1971. Allen's chart on MTBF is reproduced in "Some Radar Design Problems and Considerations," by Charles A. Fowler, in the conference record of the IEEE International Radar Conference, April 1975.

The editorials in *Science* magazine that cite examples of huge costs caused by extreme overspecification are in the issues of Nov. 19, 1993; Feb. 4, 1994; and April 8, 1994. ♦

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A long road to overnight success

Optical data storage once seemed to be failing, and the lessons to be learned from its turnaround apply to other high-tech products



For a high-technology company, launching a product is one of the most harrowing of experiences. The thrill of announcing the fulfillment of a technical vision is shadowed by the anxiety of a gambler after betting large

sums of money—and the careers of everyone involved—on the product's success.

The introduction (especially by large conservative companies) of any new product is undertaken only if the maker is convinced the market needs such an item. Yet, even when such a need is rationalized, many new high-tech products win through at a much slower pace than expected.

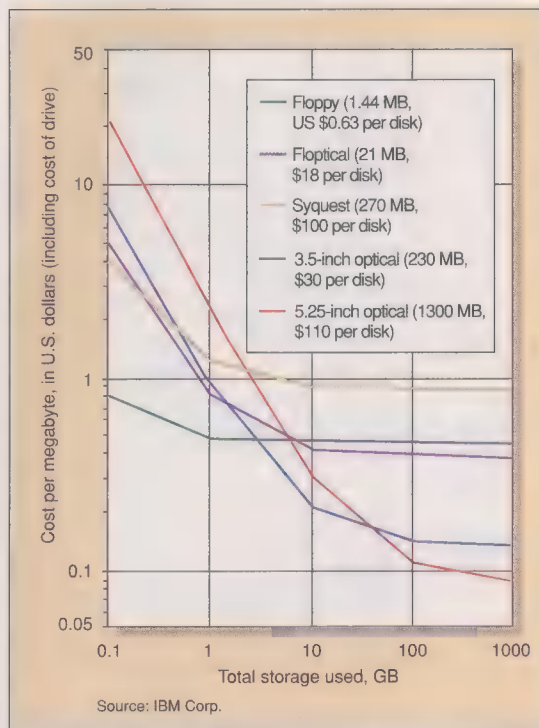
That is what happened in the optical drive industry. The high-tech product filled a market need, but success came slowly. The lessons learned from this struggle may help others in developing, launching, and marketing other such products.

FIRST, KNOW THY PRODUCT. An optical disk drive can record large amounts of computer-generated data on a removable disk (often spelled "disc" by the industry in the case of optical media). Capacities presently reach 230 megabytes on a 3.5-inch disk and 2 gigabytes on a 5.25-inch disk.

The optical drive is like a magnetic hard drive, insofar as it provides fast random access to any of the data recorded on the disk and its data rates and access times approach those of magnetic drives. Optical disks, however, outdo fixed hard disks, being removable, inexpensive, robust, and easily transportable.

Tape drives, it is true, are a less costly form of removable storage than optical drives but, being serial access, cannot match their random-access capabilities; nor can tape match the robustness of optical media, which are unaffected by magnetic fields and have a projected archival life of 100 years.

In optical disk storage, a focused laser beam writes bits on a spinning disk either



[1] When memory requirements fall below 1 gigabyte, their cost per megabyte is strongly influenced by the cost of the optical or magnetic drive. Above 1 GB, the cost of the medium begins to dominate, at which point optical storage becomes the more cost-effective technology.

once and for all or time and again [see "A typology of optical storage technologies," p. 62].

The tiny diameter of a diffraction-limited, focused infrared laser spot permits very high recording densities. Currently, rewritable optical disk drives use near-infrared lasers, with a 780-nm wavelength, to store up to 2 GB on each 5.25-inch disk.

Visible laser beams will do still better. With, say, a red beam emitting at 640 nm, capacities as high as 3 GB can fit on a single 5.25-inch disk, while a blue beam (415 nm) could pack about 5 GB into the same area.

An optical drive provides, in a sense, infinite storage. Extra room is easily acquired by adding media cartridges, at not much extra cost. Such abilities are welcome in modern computer applications. Desktop publishing, for one, can require 30 MB or more for storing one color photograph, while in computer-aided design and manufacturing (CAD/CAM), a drawing may need several megabytes. In multimedia authoring, too, 1 minute of com-

pressed 30-frame-per-second video occupies a matter of about 30 MB.

THE RIVALS. Today's best-selling type of removable storage—the 1.44-MB floppy disk—is clearly unequal to these demands. Tape is one alternative, but retrieving data from the serial-access medium is painfully slow. Optical disks combine performance and robustness, and quickly become cost effective when storage needs are large.

When requirements rise above 1 GB (or about five 230-MB optical disks), optical storage for all practical purposes costs the least per megabyte of any removable-disk drive [Fig. 1]. Floptical disks—a combination of floppy and optical technologies—currently have the highest cost of storage when capacity needs are large.

By now, the promising market for optical disks has attracted over 18 manufacturers, including IBM, Sony, Panasonic, Fujitsu, Toshiba, Ricoh, and Hitachi. But for the first five years (1987–92), shipments were disappointing. According to Dataquest Inc., San Jose,

Calif., approximately 160 000 of the 3.5-inch drives and 150 000 of the 5.25-inch type were shipped in 1992. So some drive producers failed to profit, given the slim margins on these products. Only companies with large market shares could be profitable.

FOUR OBSTACLES. There are four possible reasons for the shortfalls: unawareness of the new technology, improved competitive products, lack of industry standards, and cost to the user of adopting the technology.

Lack of consumer awareness has certainly hampered sales of rewritable optical drives. Sometimes their very existence is unknown. More often, consumers are aware of the drives but know little of their benefits and applications. There has been no extensive marketing campaign, after all, and the existence of incompatible optical technologies—like compact-disk (CD) ROM, Photo CD, and floptical—bewilders consumers.

Incomprehensibility is a problem for new high-tech products, whose benefits are apparent only to sophisticated users. So

Praveen Asthana IBM Corp.

a marketing campaign to educate the customer may be a costly necessity.

Moving targets are the second obstacle. In the early to mid-1980s, the strongest justification for developing optical storage products was their potential for holding far more data than magnetic products. In 1985, optical media's areal densities of approximately 155 kb/mm² much exceeded the 11 kb/mm² or so of magnetic types, as did their overall storage capacities. In addition, areal densities of magnetic storage seemed close to their technical limits. This impression spurred a lot of activity in the development and launch of optical drives.

In reality, though, the areal densities of magnetic storage pressed forward, far exceeding their imagined limitations [Fig. 2]. By the early '90s, the advantage held by optical over magnetic storage in areal densities disappeared, not least because of the invention of the magneto-resistive head. Since optical densities did not greatly surpass magnetic, the attempt by makers to "sell" them as a replacement for magnetic storage proved a strategic error.

The moving target is a frequent problem with high-tech products, since technological change is difficult to predict. Often, new ideas are taken from the research stage to product development because they could oust current successful products. After all, the transistor replaced the vacuum tube and the audio compact disk replaced the vinyl record. In swift retaliation, the foe ups its performance (or lowers its cost) and thus becomes harder to replace—the target is a rapidly moving one.

In high-tech development, it should be *de rigueur* to project the potential performance gains of competitive products. Assuming that the competition will stay put while the new product is moving from R&D to market is dangerous. And the time needed to achieve even minimum market acceptance can often be longer than the development time.

LACKING STANDARDS. A uniform industry standard is the third requirement for the triumph of many products. The floppy disk and the compact disk owe a large part of their acceptance to a single, industrywide standard.

In the optical drive industry, on the other hand, several disk formats and media types were introduced by several companies. This incompatibility confused customers and inhibited growth. A similar situation arose after World War II, when the simultaneous introduction of noninterchangeable 45-rpm and 33 1/3-rpm phonograph records induced a four-year slump in the music record industry.

Clearly, it is vital for all products to meet a single agreed-upon standard. A company's pride in its unique technology must take a backseat to the need for interchangeability and open systems, or else the entire industry will be stymied. The optical disk industry is learning its lesson in this area, and has recently made great progress in negotiating and establishing worldwide standards.

High initial costs to the customer have

greatly inhibited sales of optical drives. Although their storage costs are very competitive on a price-per-megabyte basis, consumers must pay a premium for the drives themselves. For example, in 1992, a 3.5-inch (128 MB) magneto-optical drive sold for in the region of US \$1500 to the end user while a 5.25-inch (1.3-GB) magneto-optical drive sold for about \$4000. The cost of a magnetic disk drive was less than \$200.

PREMIUM PRICES. Why are hardware prices for rewritable optical products so high? For that matter, why are their prices so high when CD-ROM drives, which are optical, too, only cost about \$300?

The key reason is the low volume of rewritable opticals. A product with low unit sales volume is unable to exploit economies of scale in the purchase of components. The larger the volume in which a manufacturer can buy components and raw materials, the lower the cost of each unit. Also, a product with low unit sales volume may suffer from a high fixed cost per unit. (This cost is calculated by dividing the volume of products into the total fixed cost, such as the expenses for the factory, administrative overhead, and land.)

Another factor with economic consequences is that optical products are peripherals, designed to support the primary system (such as a personal computer). Just as consequential as the absolute price of the unit is its price relative to that of the main system. In the last few years, with severe downward price pressures, costs for PCs and workstations have dropped, causing the drives to look expensive.

Companies planning to launch a new technical product might benefit from these experiences with optical drives. Since pricing is a crucial factor in the acceptance of any product, the entry cost to the consumer deserves study before the product is launched. It should be as low as possible for the value delivered whenever high unit-sales volumes are needed for commercial success. The recently launched Apple

Newton's entry price, for example, was too high for the value it delivered, and the product has not done well, despite its innovativeness and potential usefulness.

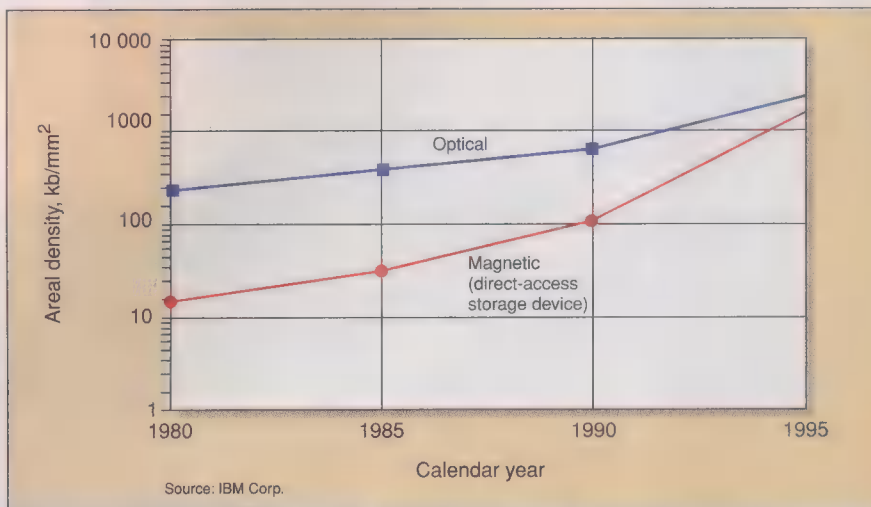
Also, if the product is a peripheral unit, it is important to consider the price of the system with which it is associated and fully understand how its pricing may change over time. The peripheral may need to maintain the same kind of price curve.

For all four of these reasons, optical drive shipments were low through 1992. By the following year, the industry had begun to understand its problems and respond by reducing the entry price (drive prices have about halved since then). Efforts also were made in opening marketing channels, increasing customer education and demand generation, and looking for applications that would appeal to consumers.

ON THE UP AND UP. With these actions, shipments of optical drives surged. In fact, this year the demand for many types of magneto-optical products is exceeding the available supply, a sign that the industry may be on the knee of the shipment growth curve. Perhaps the chief reason for the surge has been the recent emphasis on marketing by optical drive companies. The focus here has been on applications development, because it is solutions that customers buy, not hardware.

The applications that stir the most interest—the "killer" type—are those that could send sales of the product rocketing. Two examples are the Lotus 1-2-3 spreadsheet, which sparked the explosive demand for PCs in the office of the early 1980s, and the Visicalc spreadsheet program, which had the same effect on Apple II sales in the late '70s. Without a killer application, products may find success only after a long haul.

For optical drives, only now do killer applications seem to be emerging. One is electronic documentation, which addresses paper management [see Colin Maunder, "Documentation on tap," *IEEE Spectrum*, September 1994, pp. 52–56]. This applica-



[2] In 1980, the areal density of optical storage media seemed to ensure their success over magnetic disks. But before the former left the laboratory, the latter had improved greatly.

A FAMILY OF REMOVABLE STORAGE DEVICES

A variety of products fall under the umbrella of optical storage. The distinctions between the drives are not common knowledge, nor is it widely known whether the media they use are interchangeable. Still, they do have some things in common.

In the basic optical drive configuration, the output of a semiconductor laser diode is first collimated by a lens, and then given a cylindrical shape by a prism-like component called a circularizer. The collimated and shaped beam is then transmitted to a turning (45-degree) mirror, which reflects it onto an objective lens. The lens focuses the beam onto a diffraction-limited spot on the spinning optical disk—the equivalent of a phonograph stylus. The laser stylus is used at low power to read out recorded marks, and to ensure track-following and focusing-servo functions.

The objective lens that focuses the spot is mounted on a platform, called an actuator, which moves across the diameter of the disk. Thus the actuator gives the laser beam access to any data track on the disk.

A prime distinction between drives is which components are mounted on the actuator. A single-head optics design has all its optics mounted on the platform [see figure below]. In a split optics design, however, most of the optical system is fixed to the drive chassis, with only the objective lens and turning mirror mounted on the moving actuator. The main benefit of the latter design is that the actuator weighs less and so can move faster and give faster access to the data.

A more crucial distinction between systems is how they record marks. The technique used determines the drive's design and the type of media that can be used. In current 5.25-inch commercial systems, the marks are made in a heated medium with one of three processes: ablative (hole burning), thermomagnetic, or phase-change. In all these

techniques, the optical drive's laser is first pulsed to high powers so as to heat the disk medium in preparation for recording.

In ablative recording, the focused high-power laser spot burns holes in the medium. The permanency of this way of recording data is reflected in its name: **write-once, read-many (WORM) recording**.

WORM recording provides the highest level of data security available in a removable device, suiting it to many applications in government, legal, and financial data archiving. In contrast, thermomagnetic (better known as magneto-optical) and phase-change recording are rewritable processes.

In **magneto-optical recording**, the energy in the laser beam merely heats a spot on the disk past the disk material's Curie point (about 200 °C). Each magnetic domain in the hot spot—or rather, each domain's direction of polarization—becomes susceptible to the influence of an external magnetic field. When the material cools below its Curie point, the direction of polarization is frozen and thus data is recorded. Obviously, this type of recording is reversible, with over a million overwrite cycles possible.

Marks recorded in this way can be read out by laser because of the Polar Kerr effect—the fact that the optical polarization of a linearly polarized beam is rotated very slightly (0.5 degree) when reflected by a magnetic domain. The direction of rotation, depending as it does on the direction of polarization of the magnetic domain, represents the binary data recorded on the disk. With the use of error-correcting codes, the design of the read optics and electronics provides a sufficient signal-to-noise ratio to ensure an error rate of less than one in 10^{12} .

In **phase-change media**, the recording material is an alloy having two phases with differ-

ent optical properties, such as TeSeSn, a chalcogenide of tellurium, selenium, and tin, which has a crystalline phase and an amorphous phase.

To form a mark, a spot of crystalline recording material is momentarily melted by a laser pulse. Then the spot cools quickly into an amorphous-phase mark, whose reflectivity differs from the surrounding, crystalline-phase material.

Recorded marks can be erased through an annealing process, during which a continuous erase beam heats the material to just below its melting point, returning the alloy to its crystalline state.

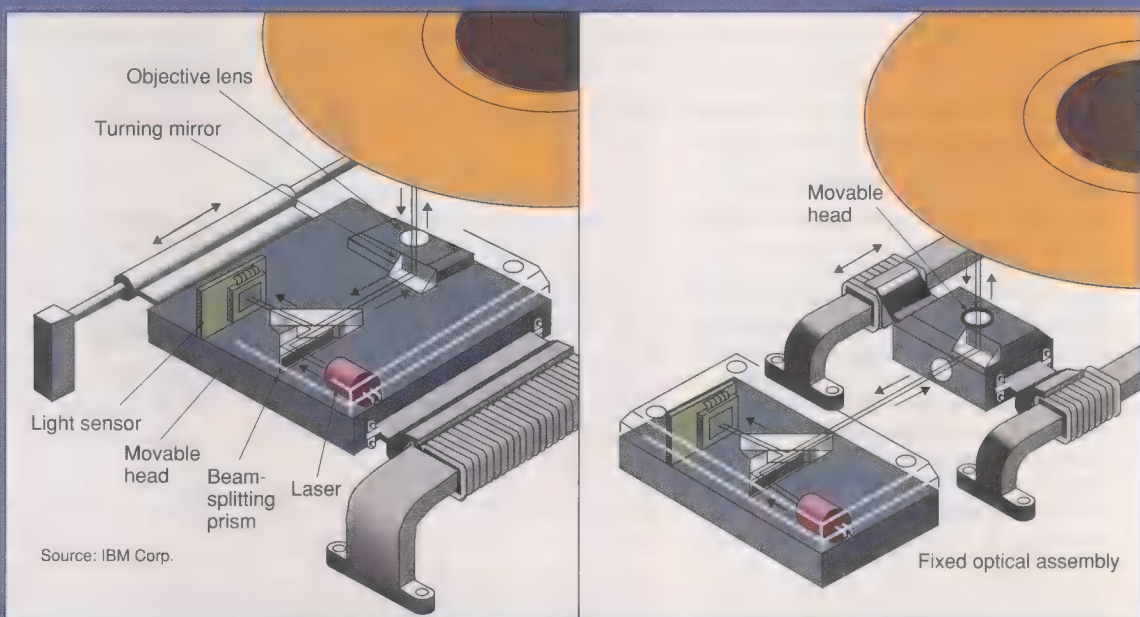
The simplicity of phase-change technology gives it an edge over the magneto-optical drives, which have more complicated optical paths and electronics. Another plus is that a phase-change drive, having no need for a bias magnet for data recording, can be made thinner and consume less power. Relative disadvantages include the medium's fewer proven overwrite cycles (about 50 000) and the rate at which the material can change phase, which constrains the data-writing rate.

Both magneto-optical and phase-change systems are available today. But drives of one type do not work with media of the other type. The incompatibility has been a source of confusion to users and a damper on market growth for both technologies.

CDs are 120-mm-diameter optical media that have recently caught on for computing. Of the three types—read-only, erasable, and in between—the **CD ROM** is the most popular. It is a read-only disk into which pits are permanently stamped to record data, much as vinyl records (or audio compact disks, for that matter) are stamped out from a master recording. To read the data on the disk, a laser stylus is shone on its surface, and the intensity of the light reflected reveals the presence or absence of a pit.

A CD ROM can store a good deal of data (650 MB is typical), but reading and writing data is

Traditionally, all drive optics have been mounted on just the one platform [near right] that is moved from track to track in order to read data. But in the latest, split-head systems [far right], the optical system's turning mirror and objective lens alone are mounted on the platform. Because of the lesser weight of the split-head's movable platform, or actuator, tracks can be changed—and thus data read—faster.



generally quite slow. Even the latest and fastest drives (4X-speed) have a data transfer rate of only 600 kB/s, and their seek time is measured in the hundreds of milliseconds.

CD-ROM drives are read-only devices and are without question the most successful of the optical drives, with unit sales doubling every year. At present, traditional optical drives do not read CD-ROM format disks, though no insurmountable technical issues prevent this.

In fact, a **CD-recordable (CD-R)** drive may be described as a WORM drive for CDs. An organic polymer on which marks are recorded by means of a phase-change process, the CD-R media can be played in normal CD-ROM drives. Conversely, CD-R drives can read CDs, but in addition read and write on CD-R media. Though fairly new, CD-R drives are winning a following as their prices plunge (their street price has dropped from about \$5000 in 1993 to \$3500 as of last March).

The CD-R drive is useful for making masters for CD-ROM manufacturing, and the disks can be used for distributing a lot of information to a small audience. But because the drives record in CD format, their performance characteristics are unattractive for data storage. The Kodak PhotoCD is a type of CD-R in which photographic images are digitized and stored on the CD disk.

On the horizon are **CD-erasable (CD-E)** systems, which one-up the recordable CD by being rewritable. There are no CD-E drives on the market at present, but some are expected soon that, like CD-R, will use phase-change media.

The rewritable **mini-disk** from Sony is an optical device, 60 mm in diameter, that uses magneto-optical technology to store up to 140 MB of data. Originally designed for digital audio recording, it now also comes in a version for data recording.

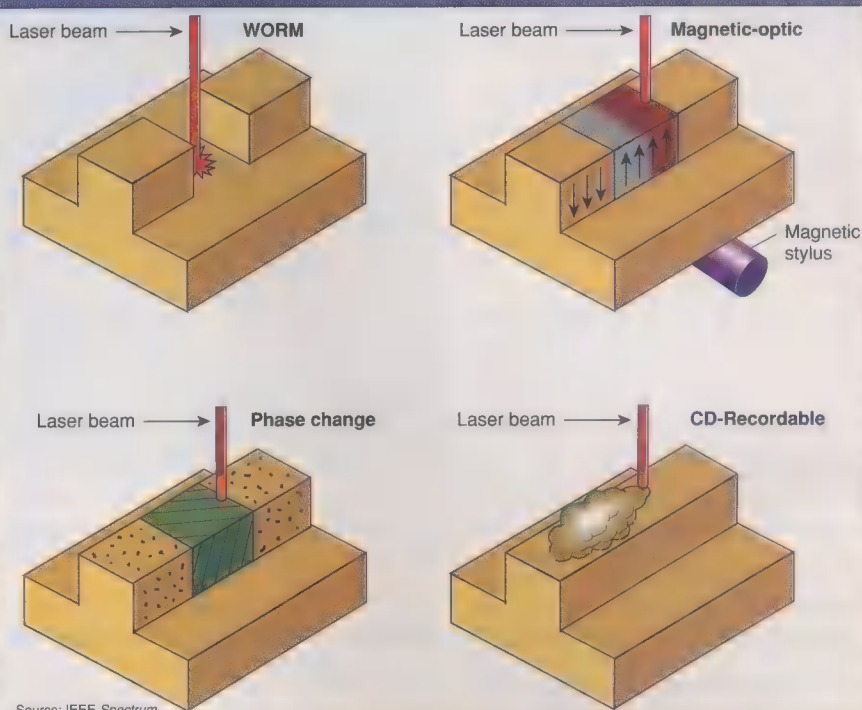
The mini-disk system's innovative features include very low power consumption and the use of pulse-width modulation recording to achieve high capacities. Further, data on the disk can be directly written over and the disk requires no separate erase pass, unlike almost all other magneto-optical drives. But the current system is very slow, both in access time and data rate, and the technology is not easily extendable to higher data rates.

A **floptical disk** is essentially a magnetic floppy disk with an optical track that can be read with a laser beam to help maintain tracking [see figure, right]. As the tracks can be packed together more closely than on purely magnetic disks, present floptical devices can store about 21 MB, or about 15 times as much as floppy disk.

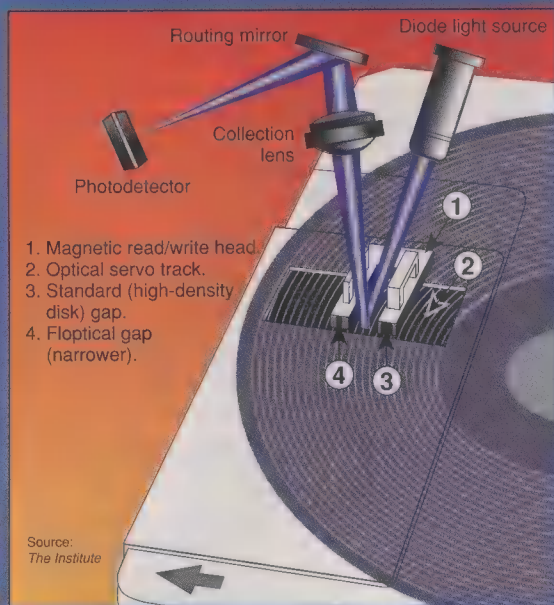
Paradoxically, a floptical drive uses neither lasers nor optics to write or read information and so is not, strictly speaking, an optical drive. It is aimed at replacing the floppy drive in personal computers.

One big advantage of floptical technology is that the drive can read ordinary 1.44-MB floppy media, so it can accept disks written by other, non-floptical PCs. However, only floptical drives can read floptical disks.

While optical disks can store more data than



Data is written on optical media by changing a spot's reflectivity. For a permanent mark, a laser pits [top left] or swells [bottom right] the medium. For an erasable one, a laser-heated spot changes chemical phase [bottom left] or lets a magnet alter its polarity [top right].



Floptical disks make use of optical technology, but not to hold data on a disk—for that job, magnetic techniques suffice. Instead, the optics serve to position the drive's magnetic read/write head with greater accuracy than can magnetic track-sensing techniques. Floptical disks as a result fit in more tracks than floppies and store about 15 times as much data.

any other removable medium of similar size, there are always those who need more capacity. For those individuals, there are optical library systems.

They resemble nothing so much as a jukebox, in that an automated loading mechanism takes disks from a large storage area and places them into one or more optical drives. These libraries range from desktop units storing 20 GB of data (16 cartridges) to refrigerator-sized cabinets storing several hundred gigabytes of data.

Optical libraries are primarily useful for data

archiving and for hierarchical storage management. This last is a method of transferring data files among types of memory in accordance with how often the files are used, so as to make the most efficient use possible of the varied abilities of cache, RAM, hard disk, optical disk, and tape. For example, seldom-used files on the hard drive are automatically transferred to an optical library for near-line storage. If these files subsequently see no activity for a certain length of time (say, one year), they are transferred to off-line tape storage.

—P.A.

tion, with its huge blocks of data, needs a high-capacity, low-cost storage technology, ideally with fast random access. Optical disk drives, of course, can store numerous document images (text and/or photos), yet they provide random access to any stored image.

Another image-oriented application that could become a killer is multimedia—the integration of video, audio, and computer data. The storage requirements of multimedia files are enormous: at 30 frames per second, just 1 minute of full-screen video (at 640 pixels by 480 and 24-bit color) takes up 33 MB with MPEG 1 compression [see “Interactive Multimedia,” *Spectrum*, March 1993, pp. 22–39].

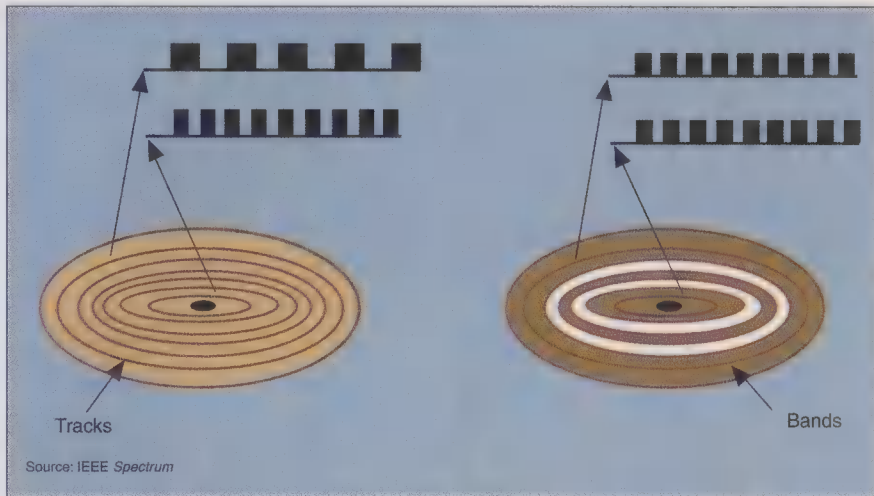
With the promise of these two applications (as well as others coming out), and the steps taken to reduce entry prices and increase market awareness, the future of optical drives is looking much brighter. Still, it will take a few more patient years before rewritable optical drives gain widespread acceptance, and patience in product launch is not popular in modern business, which usually focuses on short-term returns. An examination of hugely successful products, though, shows the importance of standing firm.

NO SUDDEN SUCCESS. New products generally fall into three classes: those for which commercial success is immediate, those to which it comes at a snail's pace, and those that fail. Products in the first category are extremely rare, while unfortunately, those in the third category are frequent in the high-tech industry.

Most success stories fall into the second category, including many “overnight successes” like the facsimile machine. Launched in the United States in the mid-’60s, the fax was shelved because it was unprofitable. When it was relaunched in the late ’70s by the Japanese, it was again a money loser until it began to take off in the mid- to late ’80s. Today, no one would question the indispensability of fax machines. Another example is CD ROM. Six years after the first one was shipped, analysts were still calling it a dead technology. Only in its eighth year (1992) did unit sales take off. In 1993, about seven million CD-ROM drives were shipped, making it a \$2 billion industry.

In point of fact, most lasting technologies have taken many years to establish a market. This has been true for products now considered obvious winners, such as color television sets (whose sales took off after five years) or power steering systems (which took 10 years to catch on). For these products, it took time for market awareness to develop, for unit prices to reach an attractive level, and for killer, or even strong, applications to be found.

Sometimes, of course, this never happens and the product dies after a few struggling years (as did Federal Express's Zapmail). But, if there is a strong, rational need for a product (even if nebulous), then triumph is eventually possible, even likely,



[3] When the same amount of data is written on every track [left], the capacity of the shortest track (the one closest to the center) is the limit for all tracks. Grouping tracks into bands and optimizing the amount stored on each band's tracks [right] doubles a disk's capacity.

if suitable efforts are made to reduce entry cost and create market awareness.

The difficulty for any engineering group lies in convincing executives, accountants, and investors (groups not known for their patience) to support the product over the long term. Japanese companies have had the forbearance to stick with such products (part of their vaunted long-term thinking) and often, as with the fax, have been rewarded for doing so. Given the long-term potential of optical storage, it is perhaps not surprising that Japanese companies make up 14 of the 18 manufacturers of rewritable optical drives.

FUTURE STRATEGIES. To keep the market growing rapidly, the optical drive industry must adopt two kinds of strategies. One is a product strategy of steadily adding to drive performance and capacity. The other is a business strategy that emphasizes reduced costs, greater demand, and new applications. To prevent technical improvements from increasing price, the strategies must be interlocked. If all this is done properly, optical should remain the fastest-growing segment of the storage industry.

Improving drive capacity unceasingly will alone maintain an advantage over alternative forms of removable storage. Data-rate increases will follow naturally (doubling the linear density should double the data rate, given the same rate of disk revolution).

In all forms of storage, the hunt for higher capacities is unending. Since the market will not accept optical disks with larger diameters, the quest points to higher areal densities, which are inversely proportional to the square of the diameter of the recorded mark. In turn, the mark's diameter is chiefly a function of the diameter of the spot made by the laser beam focused on the medium. The spot's diameter is equal to 1.18 times the light's wavelength divided by the numerical aperture (NA) of the objective lens used to

focus it onto the disk. Thus a smaller spot size requires either a laser with a lower wavelength or a lens with a higher NA.

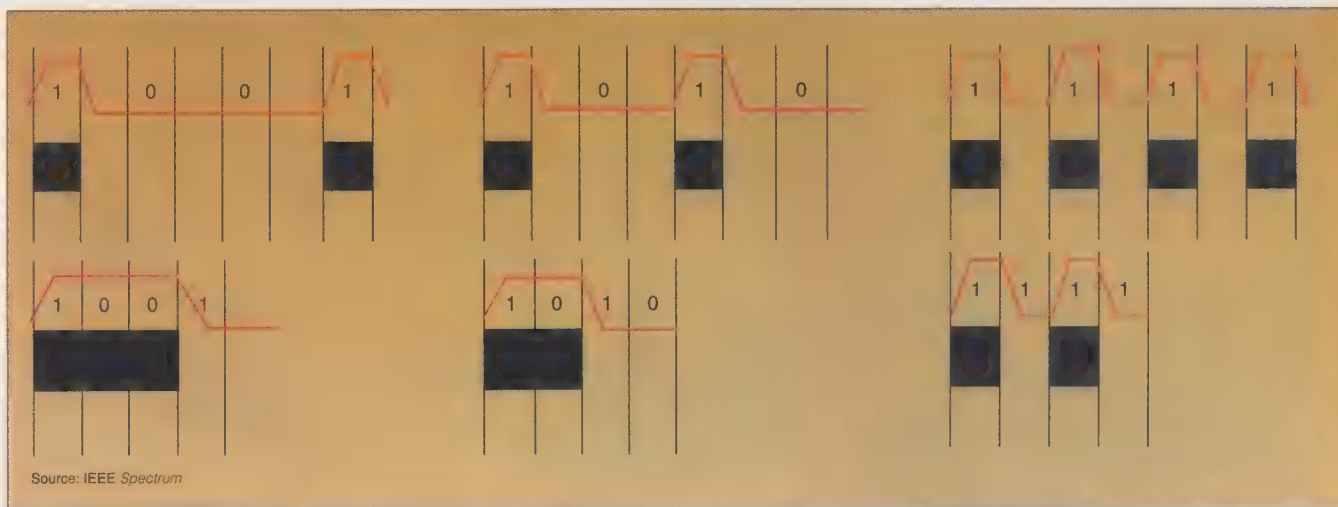
LASERS AND LENSES. Current optical products use lasers that emit light in the near-infrared range (780–830-nm wavelength). The next generation of optical drives (1995–96) will use visible lasers that emit in the 670–690-nm (red) range. Perhaps five years away are lasers that emit in the blue region (430 nm). Optical drives with such lasers will have twice as much storage capacity (about 5 GB on a 5.25-inch disk) as those with red lasers.

The use of blue lasers for optical storage came much closer to actuality in 1990, with IBM Corp.'s invention of a high-efficiency, frequency-doubled solid-state laser that could be directly modulated at high data rates. In this device, the output of an infrared pump laser is fed into a mode-matched potassium niobate (KNbO₃) cavity where frequency doubling and gain can occur. And modulating the pump laser also modulates the blue output light.

The fact that the laser could be thus directly modulated at the data rates (10–100 MHz) found in optical storage was a breakthrough in the use of second harmonic generation material for lasers. With this laser, IBM recently demonstrated magneto-optic recording at a record-breaking linear density of 3 kb/mm.

Other companies besides IBM are investing in solid-state blue-green-wavelength lasers for optical storage. Recently, Sony Corp., Tokyo, demonstrated a green laser based on frequency-doubling technology. But while this device is extremely compact, it cannot be directly modulated (an external acoustic-optic cell is used for modulation).

From the viewpoint of compactness and direct modulation capability, the ideal blue laser source would be a semiconductor diode. In this area, a research group at 3M Corp., St. Paul, Minn., has recently demon-



[4] Using pulse-position modulation [top row], a drive writes a mark on the medium for each 1 bit and leaves a space for each 0 bit. With pulse-width modulation [bottom row], the drive writes a mark when ■ 1 is sensed and stops when another is sensed, using less track area.

strated a semiconductor laser made from a II-VI material system that could lase in the 430-nm range. This device, however, cannot operate continually (in continuous-wave mode) for any length of time unless cooled to cryogenic temperatures.

At present, commercial optical drives use objective lenses with a numerical aperture of 0.55. Since increasing the NA makes things awkward for the focus and tracking actuators, lasers with shorter wavelengths are preferable.

Increasing the NA affects ■ lens's depth of focus even more than the spot size (the depth of focus is inversely proportional to NA^2). Optimizing the depth of focus is important because it sets the acceptable degree of tilt of the media, as well as the quality required of the actuator and servo system (the smaller the depth of focus, the better the actuator and the servo have to be).

As servo system and actuator designs are refined, the use of objective lenses with NAs over 0.55 becomes more feasible. Probably the next jump will be to an NA of 0.62, which will yield a spot with ■ 12 percent smaller diameter than would an NA of 0.55.

BAND WAGONS. Nonetheless, if optical storage is to remain competitive with alternative forms of storage, other technologies need to be implemented in conjunction with, or independently of, changes in wavelength and NA. Some have already been implemented in commercial systems.

To start with, there is track utilization. In the first generation of optical products (that is, 650-MB 5.25-inch disks), the amount of data on each track was kept constant and equal to the linear capacity of the innermost track, thus underutilizing the longer outer tracks but keeping the number of bits read per second constant. When the second generation appeared last year, the primary method used to double capacity was banded or zoned recording [Fig. 3]. The disk is divided into several radial bands (presently about

16). While the linear density for each track in a band may be higher or lower depending on its position, the overall linear density is the same for all bands. Thus, each successive outer band stores more than before.

The electronics required for the readout of ■ banded disk are more complex than for a nonbanded one. The reason is that the bands, though having the same linear density, each have a different linear velocity (which is a function of the radius and the angular velocity) and hence ■ different data rate. In current optical drives, for example, the data rate varies from about 1.2 MB/s at the inner band to about 2.3 MB/s at the outer band. To accommodate this variation, the channel must have ■ variable clock and equalizer.

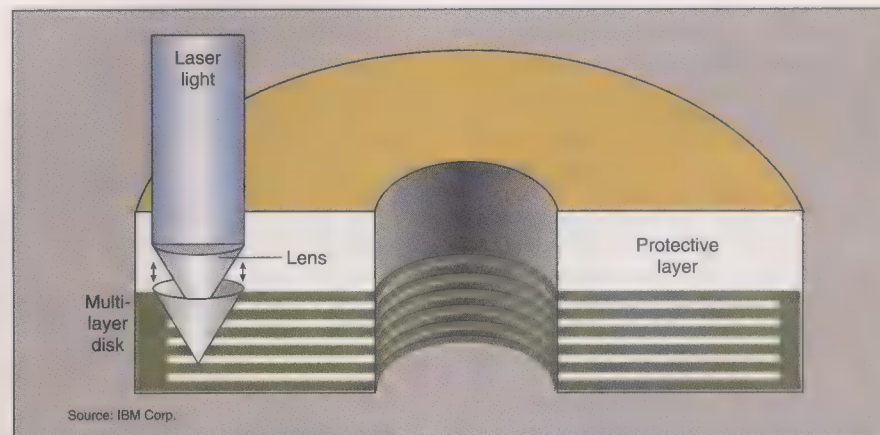
Moving on to the next point, improved modulation techniques can also increase storage density, by 50 percent at least. Most current optical drives record data using pulse-position modulation (PPM), in which a mark signifies a binary 1 and its absence sig-

nifies ■ binary 0. So with PPM, a 1001 bit sequence is a mark-space-space-mark.

In pulse-width-modulation (PWM) recording, the edges of the mark represent the 1s so the need for spaces (and the space they take up) is reduced. Thus with PWM 1001 becomes ■ single mark that takes less room than PPM's marks and spaces [Fig. 4].

Multilayer storage is another idea whose time may have come. In May of this year, IBM demonstrated an optical disk containing multiple writable layers [Fig. 5]. Because the depth of focus of the objective lens is very small, layers can be read separately without cross talk. Moving from one layer to another requires only a slight shift of the objective lens.

IBM's disk has four layers, but in theory 10 are possible. Multilayer technology could expand bit capacity with the least technical risk of any approach. Before products with multilayer capability are introduced, however, industrywide interchange standards need to be in place.



[5] Multilayer data storage stacks several layers of transparent optical media into a single disk. Because laser light can be focused not just on the disk surface but to the right depth below it, data can be read from any layer by the disk drive. To date, four-layer disks have been demonstrated and could be available next year; 10-layer disks are also theoretically possible.

Optical superresolution, which exploits the diffraction properties of focused beams, is being tried out. In this case, if the collimated beam of light incident on the objective lens is in the shape of a ring, the spot size of the focused beam will be smaller than if no light were blocked. In essence, energy has shifted from the central, or zero, order to higher-order side lobes. If these side lobes are not too big, this is an effective way of shrinking spot size. The price is loss of the blocked optical power.

Magnetic superresolution (MSR) is a technique recently invented by Sony. While the standard magneto-optical disk has one magnetic layer, an MSR disk has two—memory and readout. When the readout layer is heated past a certain threshold, the process called magnetic exchange coupling copies information into it from the memory layer, for use by the readout beam.

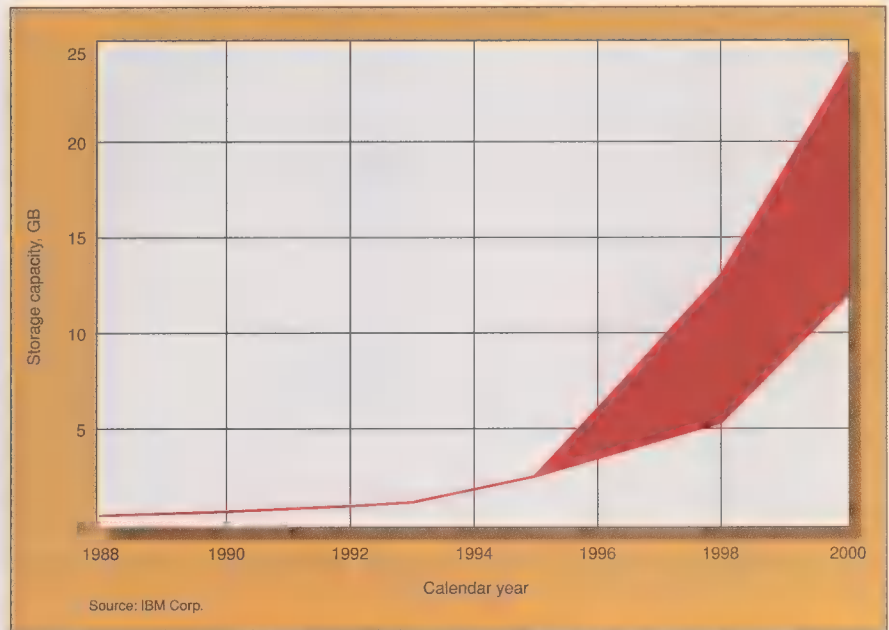
The thinking here is that a focused beam has a Gaussian energy profile: the energy decreases with increasing radius. Thus, if the tip of the beam alone is "hot" enough to raise the temperature of the readout layer, only a small region will be heated sufficiently and the resulting readout mark will be tiny.

Even the read channel as such has not been overlooked. This channel in a data storage device is the set of electronics that process the detected read-back signals from the disk and extract the digital data from the (often noisy) analog waveform. Nowadays optical drives use an analog channel to do this processing, which, however, starts to become ineffective above linear densities of about 1.2 kb/mm. At high linear densities, an intersymbol interference (ISI) smears the analog waveform and makes it harder to distinguish the separate marks, especially in the presence of any noise.

The answer is a partial-response-maximum-likelihood (PRML) channel. This digital channel uses an algorithm to sample the waveform, filter out noise, and extract the digital information. It can therefore allow much higher linear densities to be implemented than an analog channel.

The PRML concept has been known for some time; such a channel was used by the National Aeronautics and Space Administration to communicate with space probes. But only recently have the costs of the electronics fallen sufficiently for this channel to be implemented in affordable optical and magnetic drives.

To list one last embryonic product improvement, most optical disks consist of tracks separated by grooves and data is recorded either in the grooves or on the tracks (lands). Why not on both? Because there is cross talk between data on adjacent lands and grooves. Consequently, several companies have suggested cross talk (and noise) cancellation algorithms. Matsushita Electric Industrial Co., Osaka, Japan, for example, recently demonstrated such an algorithm and was able to double density.



[6] The bit capacity of 5.25-inch optical storage media is ready to rise significantly in the next few years. Whether it takes off at the steeper or gentler slope will depend on which of the possible technologies for improving capacity [see table below] turn out to be compatible.

Improving optical storage densities

Technology	Growth factor ^a	Comment
Multilayer medium	4.0	1995 technology
Blue laser (430 nm)	3.8	1998 technology
Land and groove recording	2.0	Demonstrated by Ricoh and Panasonic
Magnetic superresolution	2.0	Demonstrated by Sony
Banding	1.5	Incorporated in 1993 in 1.3-GB disk
Pulse-width modulation	1.5	Planned for a 2.6-GB product in 1995–96
Optical superresolution	1.4	Reduces laser power available for recording
Numerical aperture of 0.65	1.4	Makes demands on the actuators and on producing disks without tilt
Partial-response-maximum-likelihood	1.3	Digital channel now used in a few hard drives

(a) In terms of areal bit density.

To summarize, not only does each of these technologies raise storage capacity well above the 650 MB of first-generation, 5.25-inch optical products [see table], but many of them can also be used in combination. Therefore, gains in optical storage capacity in the near future may be quite substantial [Fig. 6]. A range of capacities is possible because certain technologies may be incompatible.

In choosing technologies, maintaining backward compatibility is important. The drive should be able to read and write one previous generation of disks and read two previous generations.

TO PROBE FURTHER. To explore concepts of new product management, read *Design and Marketing of New Products* by Glen Urban and John Hauser (Prentice Hall, Englewood Cliffs, N. J., 1993). *Inventivity* by John Gilman

(Van Nostrand Reinhold, New York, 1992) looks at how long adopting new products takes.

Optical Recording by Alan Marchant (Addison Wesley, Reading, Mass., 1990), gives an excellent overview of the optical-storage field. The March 1994 issue of *Byte* magazine contains several articles on the future and state of the art of magnetic and optical storage.

Finally, almost any elementary book on managerial accounting can help in understanding the costs of produced goods. A knowledge of accounting can only improve an engineer's corporate effectiveness. ♦

ABOUT THE AUTHOR. Praveen Asthana is a program manager in business and product strategy at IBM Corp., Tucson, Ariz. His current research interest is in developing an effective means of reducing the market acceptance time for high-technology products.

Survival of the fittest

Occupational health is similar to physical health—you have to keep working at it and looking ahead, and not put off responding till symptoms of trouble are obvious



Illustrations: Liam Roberts

Staying in good physical shape has a lot in common with maintaining technical fitness. For one thing, they are both ■ struggle. The key to technological fitness is having the right skills at the right time at the right cost—one that is better than your competitor's. Nothing can guarantee employment, but much as you can improve your muscle tone, your heart rate, and your flexibility, you can improve your competitive position at work. The trick is to think systematically about the way you identify and develop the technical skills you need. For our purposes, abilities, competencies, know-how, expertise, and proficiencies are the same ■ skills.

Our six-step skill-development process, based on the analogy between physical and technical fitness, will force you to take the initiative and work with management to align its needs with yours. Although you are probably familiar with some of these steps, implementing all of them together, in a conscious way, will help you avoid the haphazardness of the procedures traditionally used by technical professionals. The process consistently focuses on skills, not on course titles or technology topics. It requires you to think about the benefits of each skill you propose to learn and to set priorities among those skills. It provides for an early management buy-in. It creates ■ formal way of optimizing educational methods. Finally, it integrates learning with work. If you don't currently have ■ job, the same six steps can be adapted to the task of helping you get one.

FITNESS CONCEPTS. Physical fitness, or wellness, means maintaining a healthy life style, not just responding to symptoms; technical fitness means actively keeping the right skills up to speed, not just responding to deficiencies after they have been noted.

David B. Youst Phillips Training Systems
Laurence Lipsett Consulting industrial psychologist

Physical fitness also involves harmoniously balancing nutrition, exercise, stress-management, and environmental control; technical fitness involves balancing the many activities needed to acquire new skills.

Moreover, to achieve physical fitness you must act on changes in the way we understand our internal and external environments: for example, new knowledge about basic food groups, cholesterol, and second-hand smoke has transformed the way we choose food and assert our right to breathe clear air. To achieve technical fitness, as well, you must routinely evaluate and respond to technical and workplace changes. Then, too, your capacity to improve your physical fitness rises as you become more fit, very much ■ technical professionals who continually set themselves new skill-development challenges get better at meeting them.

Finally, what most of us know about fitness—both physical and technological—has far outstripped the average ability to profit from it. The U.S. Surgeon General pronounced smoking ■ health hazard more

than 30 years ago, yet countless teenagers start smoking each year. Most technical professionals know several steps they should take immediately to improve their technical fitness, yet they do not take them. For example, 100 percent of more than 365 technical professionals responding to a questionnaire on obsolescence said that they should be spending more time developing technical skills. The problem is that technical fitness requires the same kind of individual discipline—focus and follow-through—that physical fitness requires.

COMMON PROBLEMS. The obstacles to technical fitness are many, and increasing.

One obstacle is the rapidly changing workplace. Such organizational changes as downsizing, flattening, speeding up, going global, teaming, and outsourcing profoundly affect your ability to develop new skills—often adversely.

Another problem is information overload. The rate at which technical information expands is accelerating. According to Peter Large, the author of *The Micro Revolution Revisited*, more new informa-

tion has been produced in the past 30 years than in the previous 5000.

Fuzzy targets will also slow down your efforts to stay technologically ahead of the pack. Many professionals adopt such unclear goals because they think that this will help them keep their options open. Others resist setting tangible targets in the belief that changes are occurring so quickly that plans are outdated as soon as they are conceived.

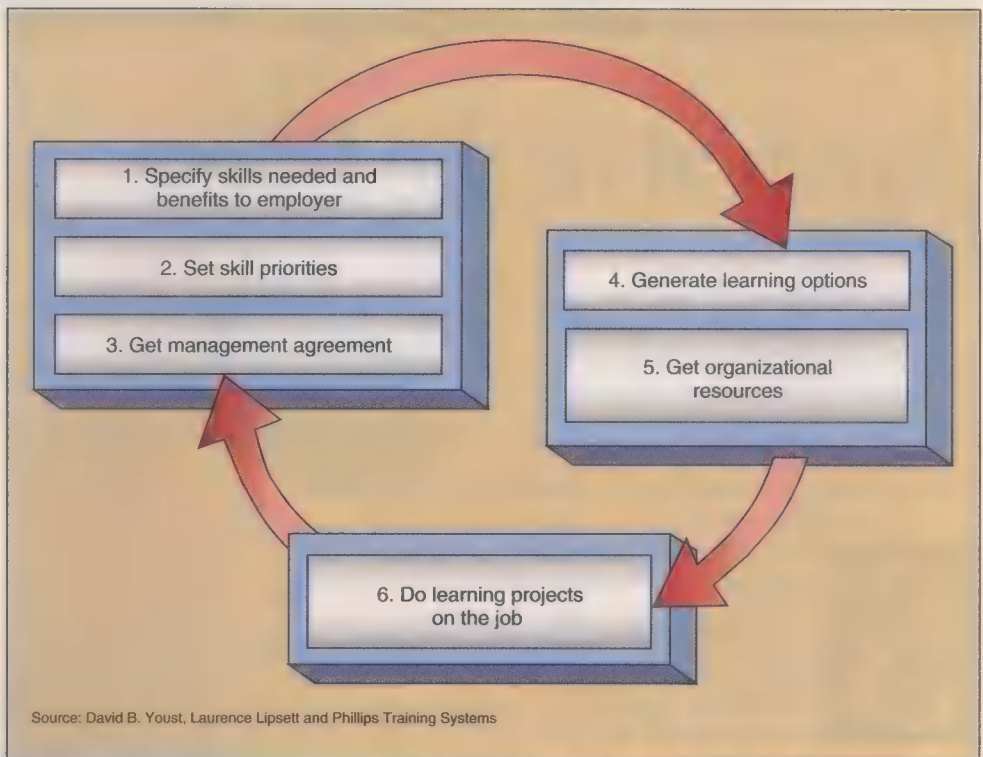
Last, there is the problem of haphazard learning processes. Too often, technical professionals have no skill-development plans whatever. Too often, course titles are chosen from corporate or vendor catalogs because they sound interesting or happen to fit time and location constraints. Too often, training is an isolated event, not a sequence of learning activities that promote improved work performance.

Technical fitness, like physical fitness, is a moving target: you must constantly achieve higher levels of performance, and so must any company that employs you. Companies that failed to meet that challenge no longer provide jobs for technical professionals or anyone else.

Within companies and their subunits, the needed skills are changing rapidly. We know some engineers who refused to see the signs when their large international company took its first steps toward leaving the plant-construction business. They were not receptive to offers of retraining for jobs in other engineering areas. When their department was closed down, a few months later, they were laid off, for they had failed to understand the importance of keeping their own skill development in sync with the changing needs of their employer.

GETTING STARTED. Before you start a new approach to fitness, use fitness concepts to think about the way you identify and learn new skills. In effect, give yourself the technological counterpart of a thorough physical exam. Consider not only your weaknesses but also your strengths and the processes that produced them, for those processes may be the very ones that will help you expand your base of skills. Here are some other ways of getting started:

- "Fire yourself" as a fitness check. Suppose that, suddenly, you were on the street looking for a job. What skills and knowledge could you offer potential employers? Who would pay for them? What could you do to get up to speed if you lacked certain requirements for re-employment?
- Review current job requirements and develop concrete plans to meet them. You



An organized approach to acquiring new skills is more likely to succeed than a haphazard one. The approach suggested here breaks the task down into separate blocks comprising six steps.

must have three priorities: first, to improve any skill that is below acceptable levels; second, to achieve peak performance on your current job by comparing your work with that of acknowledged expert producers; third, to build skills for the future. This "fix, peak, future" approach uses benchmarking, competitive assessment, and feedback from informal and formal appraisals.

- Develop a five-year work vision by writing a description of the kind of work you want to be doing and the kind of work environment in which you want to be doing it. Provide enough detail to avoid the "fuzzy target" problem: include such items as the skills you want to use, both specialist and generalist; the pay, benefits, and perks you expect; the employers who might hire you; your competitors for this type of job; and the skills you must learn.

- Seize the day. Many companies these days actively encourage professional employees to take the initiative and assume greater responsibility.

SIX STEPS. You can use the six-step skill-development process described hereafter to improve your technical fitness [see figure above]. With some individual tailoring to fit your own requirements, it can improve your performance and the effectiveness of any organization you serve.

1. *Identify your skill objectives* and write down the benefits, both to you and to your employer, of meeting them. Your list should balance technical and personal skills, the need for depth and breadth, and

short- and long-term pressures.

Link each skill objective with a reason for learning it; when benefits are explicit, trade-offs are easier to manage. Those benefits should be stated in the language your managers use—"savings," "shortened cycle times," "better customer service," "meeting department objectives," "improving competitive position," and the like—because your object is to get management support for continuing skill development. Usually, it is easier to set priorities if you quantify the benefits in dollars or in some other way. But don't avoid mentioning important benefits merely because they are hard to quantify. Regardless of how a benefit is stated, it should make good business sense, and it should be honest.

Your skill objectives should be specific—not too general or too detailed. They should be challenging but attainable, related to work performance, clear, and important. Stress skills that are critical to improving your work performance and impact. Seek out feedback, including formal and informal appraisals of your work from bosses, co-workers, suppliers, and customers.

Ask your employer for recommendations, and tune in to such company buzz words as Total Quality, teams, diversity, and core competencies—the forces that will drive your organization. Search for technologies likely to become more important to your job, company, industry, field of preparation, and career. Anticipate the skills that your company may need as a result of likely organizational changes. Investigate the standards of

preparation, codes of conduct, and recommendations for continuing education that are current in your profession. Include skill objectives that are important to your future work interests.

2. Set skill priorities. No matter how hard you try, you can't learn everything you want, and in all likelihood you also won't be able to get your manager to spend a lot of time listening to your plans to acquire a great many skills. Experience has shown that five to seven skills can be discussed effectively during brief meetings.

Rank your list of skills and benefits to provide a common starting point for ongoing discussions with management. Ranking also offers a way to build in important long-term learning objectives—those that are usually left off short-term lists.

3. Get your management to agree to your list of priorities. An early buy-in keeps you working with management; it also helps you to incorporate managerial suggestions into your plan and to align your individual interests with the needs of your company.

At this stage, your goal is to get agreement about what skills you should develop, before talking about how you will develop them. Many technical professionals find it difficult to separate this step from the fifth step—the meeting to get resources. Busy managers, they think, want to make decisions quickly. More experienced technical professionals believe that a separate third step prevents conflict when resources are cut and helps managers exercise their people-development responsibilities.

4. Generate learning options by outlining two possible ways of developing each skill on your list. The first should be the most effective one, regardless of cost; the second, the one that is cheapest and makes best use of available resources. By creating alternatives, you give management the opportunity to match resources with priorities. Often, the final plan draws from both options. Since any approach that may be chosen will help you reach your skill objectives, you are in the win-win position of negotiating among acceptable alternatives. Be sure to include challenging new work tasks, because they provide an important way to learn new skills.

5. Get a commitment of organizational support and resources. Here the rubber meets the road. You now propose the budget and preliminary plan for a series of skill-building activities. Dollars are usually less important than time. Since the availability of resources is subject to change when you least expect it, you want the ability to manage change in cooperation with management.

6. Finally, implement your plan. Your goal is to use project management techniques to reach your skill objectives, building accountability and organizational communication into the effort by setting performance, schedule, and cost objectives similar



to those of other work projects. This kind of learning project can be intensive and carried out in the short term, or it can take place more casually over a longer period of time.

In general, several learning activities will be needed to reach each objective. Time and resource requirements, schedules, deliverables, milestones, acceptance criteria and measures, and review dates are then established for each learning activity. Tracking, reporting, and change procedures must also be specified for the project as a whole. Ideally, the results from a series of projects help formulate the next learning targets, and the six-step cycle is repeated.

THE ONLY WAY. The six-step skill-development process helps technical professionals to balance all their work responsibilities and tighten up their traditionally haphazard approaches to learning new skills. Continuous skill development—the only way to

remain employable—is one of the most valuable processes technical professionals can undertake. Although some skills have fairly short useful lives, the ability to learn new skills quickly and effectively has always been useful and always will be. If you can improve the way you learn, in other words, you will make yourself more employable than you will by concentrating only on what you learn at any given time, for you will reduce the time needed to learn new skills in the future.

It isn't simple. Fortunately, you can apply the quality improvement methods you already use in business and manufacturing operations to your own skill-development process. Make obvious fixes quickly. Improve through stages by running the process consistently, reducing variability, and improving your process capability. If possible, leapfrog current methods with innovations. Measure key process variables, for what is measured improves. Few people operate their skill-development processes in a consistent way. The greatest gains come from establishing standard procedures and spending more time focused on skill development.

Every individual's process is unique. Some people have to get better at filtering huge amounts of technical information. Others need to initiate "learning networks" and to spend more time forecasting technical needs. Still others have to work on resolving the difference between their career dreams and career realities. Some "systems integrators" will spend a lot of time putting all the pieces together. In short, developing and maintaining technical fitness requires a coordinated and cohesive approach, just as developing and maintaining physical fitness requires the right blend of nutrition, exercise, stress management, and positive purpose.

TO PROBE FURTHER. Daniel Burris's *Technotrends* (HarperCollins, 1993), describes 20 core technologies and 24 ways of applying them to work in the future. *Information Anxiety*, written by Richard Saul Wurman (1989), provides many examples of information overload and offers advice on how to cope with it. *FUR*, by Harry I. Forsha (ASQC Press, 1992), supplies practical illustrations of tools designed for quality improvement, quantitative control or tracking, and appraisal.

ABOUT THE AUTHORS. David Youst, a training consultant with Phillips Training Systems, has worked as an engineering training manager at Corning Inc. and as a member of the technical staff at Kodak's Research Laboratories. His recent projects include ISO-Baldrige quality assessment, quality architecture, and ISO 9000 implementation and documentation.

Laurence Lipsett, a consulting industrial psychologist in Rochester, N.Y., is the author of four books and 40-plus articles on human resources, as well as a former professor at Empire State College and Rochester Institute of Technology.

Discipline, attention to detail, a sense of artistry, and knowledge of many fields are the keys to Alfred Yi Cho's professional success

A photograph of his, on the theme of "the world and its people," was on display in the Kodak pavilion at the 1964-65 World's Fair as among the 100 best in the world. The crystal-growth technique that he turned into a marketable technology—molecular beam epitaxy (MBE)—is behind many of the semiconductor lasers to be found in CD players around the world. For that feat he received the 1993 U.S. Medal of Science and the 1994 IEEE Medal of Honor.

The man is Alfred Yi Cho, as accomplished in painting, calligraphy, and photography as in the engineering of semiconductor materials. "There's a lot of art in science. It's not just equations and formulas," declared Cho, 57-year-old director of the Semiconductor Research Laboratory at AT&T Bell Laboratories in Murray Hill, N.J.

"Oriental art is as much discipline as anything else," observed his former colleague John R. Arthur, now professor of electrical engineering at Oregon State University, in Corvallis, who holds the fundamental patent on which Cho has based his life's work. "Eastern calligraphy requires a person to sit in front of the paper and practice over and over and over again. Al combines Eastern art and philosophy into Western technology, and that explains his success."

Meticulous. Disciplined. Persistent. Hard-working. Determined. Those words recur in descriptions of Cho by colleagues, former managers, and friends. Cho's usual work week runs from 8:00 AM until 11:30 PM Monday through Friday, with a short day—9 to 5:30—on Saturday. A two-week vacation in August was his first in 18 years.

"For years I knew I could come in on a weekend and Al would be in his lab," said Morton Panish, now a retired distinguished member of technical staff living in Spring-

Trudy E. Bell

Senior Editor

field, N.J. He was Cho's manager for the 17 years he headed the materials science research department until he stepped down in 1986. "I got him the money and left him alone. He couldn't be directed. He *knew* what he wanted to do, and he did it. Al ran his own show completely."

"How hard you work is still the most important ingredient for success," Cho affirmed. "I've always wanted to do my best so that later on I would have no regret that I didn't try my hardest."

CHILD ART. World War II gave Cho an unexpected chance to study Chinese painting and calligraphy under a grand master. He was 6 years old, and his parents and siblings had fled to Chung King to escape the Japanese invasion. Cho himself was left behind with his grandparents in occupied Beijing, his birthplace. His grandfather was a famous calligrapher of the Jangtsao school (an exceptionally ornate style of calligraphy), and he taught Cho the art. While other children were playing, the young boy was grinding the ink and pulling the paper at a steady rate as his grandfather painted the characters.

Four years later, in 1947, the family was reunited in Shanghai. But their serenity was short-lived. In two years they were again on the run, this time from Communist rule. They reached Hong Kong with few possessions.

In Hong Kong, Cho entered Pui Ching High School, a Baptist institution known for its scientific training. Since Hong Kong was run by the British, Cho needed an English first name; he chose Alfred because of his interest in the 9th-century Saxon king Alfred the Great. In addition to the compulsory religious courses, Cho took formal lessons in Chinese painting at Pui Ching. He also received an excellent scientific education, as did his classmates Dan Tsui and Lu Sham, who went on to make names for themselves in multilayer quantum-well and superlattice physics.

CHINA NEEDS ENGINEERS. Why science instead of art? "My parents said what China needs most are scientists and engineers, not artists," Cho recollected. His father, a graduate of New York City's Columbia University, had been an economics professor in Beijing; an uncle had

graduated from London University in business and banking. In part because of family pressure, Cho's older brother entered mechanical engineering, his older sister became an architect, his younger brother went into physics, and "that left electrical engineering for me."

Cho's parents wanted their children to go to college in the United States. Pui Ching High School's minister, Eunice Short, had a sister who was the foreign student advisor to Oklahoma Baptist University in Shawnee, Okla. The university awarded Cho a scholarship, and he entered as a freshman in 1955. His first impression was that "the science was very easy" and he

"wondered how the United States was so advanced." But soon Cho realized that OBU was not an engineering school.

FIRST ION BEAMS. In his sophomore year, Cho transferred to the University of Illinois, where keen competition and high technical standards came as "a culture shock." He received his BS in 1960 and his MS the following year working with his physical electronics professor Chuck Hendricks on building vacuum systems and making ion beams to study surfaces.

By this time, Cho's parents were living in Los Angeles, and after receiving his master's degree, he took a breather of four years to join them. In Redondo Beach, Calif., he accepted a job at TRW Corp., where he worked with Haywood Shelton. Shelton, a Massachusetts Institute of Technology graduate, had been charged in these early days of the U.S. space program with developing ion-beam propulsion for space travel.

Cho's years at TRW were crucial to the work he did later building the first practical MBE systems. In an ion-beam engine, cesium ions were formed by passing atoms of cesium through a heated porous tungsten plug. Understanding the atoms' reaction to the tungsten surface was critical to making an ion beam efficient enough for propulsion. Moreover, the tungsten plug was surrounded by a tantalum heat shield, the experiments were conducted in an ultrahigh vacuum, and the ion beam was surrounded by a cold shroud of liquid nitrogen to simulate outer space. Thus, although the ion-beam engine never became practical, this work provided Cho with es-



Who's Who

Name: Alfred Yi Cho

Date of birth: July 10, 1937

Place of birth: Beijing, China

Height: 170 cm **Mass:** 69 kg

Family: wife, Mona Willoughby; son, Derek; daughters, Deidre, Brynna, Wendy

Education: BS, MS, Ph.D. in electrical engineering, University of Illinois, 1960, 1961, 1968

Musical instruments: harmonica, "a little guitar"

Favorite writers: "I don't have enough time to finish reading technical papers."

Languages spoken: English, Mandarin, Shanghaiese, Cantonese, Fukin

Religion: Baptist

First jobs: dishwasher, draftsman, assembly-line worker: "All work gives you insight."

Fellowships: the IEEE, American Physical Society, and American Academy of Arts and Sciences

Distinguished memberships: the National Academy of Sciences, National Academy of Engineering, and Academia Sinica, Taiwan

Awards: the IEEE Medal of Honor, 1994; the National Medal of Science, 1993

Other achievements: author of more than 400 papers, holder of 48 patents

Hobbies: oil and watercolor painting, photography, Chinese calligraphy, table tennis, golf

Favorite quotation: "Don't work too hard, just work hard."

sential experience with heat shields, vacuums, and cryogenic systems.

RETURN TO SCHOOL. Cho's professor at Illinois, Chuck Hendricks, wasn't about to let such a promising student go with only a master's degree, and managed to get him readmitted to Illinois. "I brought back my experiment from TRW—the interaction of atoms with solid surfaces—and my thesis was very closely related," Cho recalled.

It was during this period that Cho's personal life also changed. In the women's wing of his graduate dormitory lived a music student named Mona Willoughby, whom Cho often met in the dorm's lounge. The physicist and the vocalist became close, and in June 1968—after she received her master's degree—the two were married on campus.

Upon receiving his doctorate in February 1968, Cho had eight job offers—including one from TRW, which wanted him back. Another was from Bell Telephone Laboratories (now AT&T Bell Laboratories). "I had heard so much about Bell Labs as an eminent research institution that it was a very easy decision," Cho recalled. It was one that determined his career from then on.

EARLY DAYS AT BELL LABS. John Arthur, then a member of Bell Labs' technical staff under Panish, had by this time made some fundamental observations about the interaction of gaseous atoms with solid surfaces. Specifically, Arthur was studying the interaction of beams of gallium atoms and arsenic atoms with solid surfaces of gallium arsenide. He had established that if the vapor pressure was high enough, atoms and molecules would be deposited on surfaces and build epitaxial films—that is, films that follow the crystal structure of the substrate. For this observation, in 1971, Arthur was issued U.S. patent 3 615 931, "Technique for growth of epitaxial compound semiconductor films."

But back in 1968 the usefulness of the technique—which Cho named molecular beam epitaxy in 1970—was not at all obvious. What was clear, however, was that the phenomenon warranted further investigation. "We were simply looking for people with talent to study the subject and to use it as a basis for their own activities in the field," recalled John K. Galt, former director of the Solid State Electronics Laboratory, at Bell Labs, and now retired in Albuquerque, N.M. Galt liked the fact that Cho was "a vigorous intellectual—that is, someone who pursued subjects with great vigor and was always working on something."

From Cho's first months at Bell Labs, he and Arthur "got along famously," as the latter recalled. However, their working styles were diametrically opposed. "I tend to be impulsive, to work in a kind of intuitive way, cutting corners, leaping ahead," Arthur re-

counted. "Al was a lot more methodical and careful, suggesting that we keep track of things a bit more. I think we complemented each other really well."

Their angles on the research were different as well. Arthur wanted to experiment with monolayers of material, using MBE as a technique for studying the physics of surface interactions. Cho preferred to concentrate on growing multiple layers of material, to see whether MBE could be used in making semiconductor lasers and other devices.

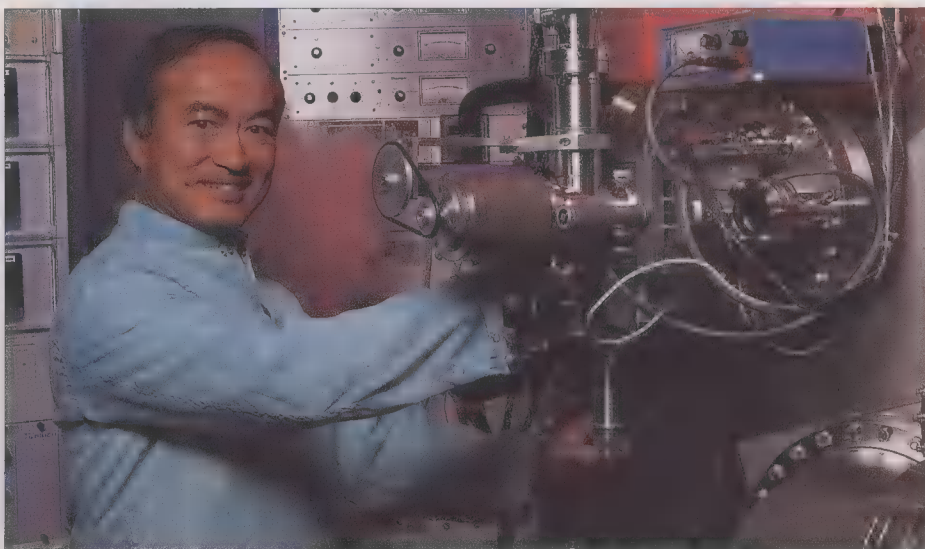
Arthur "had the scientist's outlook while Al had the engineer's outlook," Panish remarked. This was a difference blessed and encouraged by Galt, who recognized that the ideal way to develop a new technology was indeed to develop a tool and study the

GaAs laser made by LPE.

But LPE had distinct problems. Paramount among them was the difficulty of controlling the thickness of the epitaxial film uniformly across the entire surface of a wafer, and making the process repeatable enough to grow devices that were identical from one wafer to the next.

In any kind of device, the layers of semiconductor material need to be essentially free of defects—no dislocations in the crystal lattice, no vacancies where atoms ought to be. But in the early days, the materials grown by MBE were so full of defects that they were insulators. "They were so bad," Cho recounted, "that carriers [electrons and holes] could not be introduced."

To improve the quality of the materials,



Alfred Y. Cho of AT&T Bell Laboratories in Murray Hill, N.J., releases liquid nitrogen coolant from an ultrahigh vacuum system of a molecular beam epitaxy (MBE) machine. Cho developed the MBE semiconductor-preparation process used to make most of the lasers in the world's CD players.

fundamentals simultaneously.

BYPASSING COMPETITION. "When you try to introduce any new technique, you're always facing armies of well-established techniques. You have to prove that your budding flower can compete with a tree," Cho observed. "So you have to do as well if not better [than they] even before you have a chance." That requires that you "believe in yourself and have the persistence and determination to make it work. Most important of all, you have to like your work and know where you're going."

The established crystal-growing technique in the late 1960s and early '70s was liquid-phase epitaxy (LPE). In LPE, semiconductor crystals were grown on a substrate from liquid. Special structures were then etched into the crystals by applying acid through a mask of the desired shape, and new crystals were grown on top. For electro-optical devices, LPE was quite successful. In 1970 Panish, along with Izuo Hayashi, had demonstrated the first room-temperature continuous-wave (as opposed to pulsed) heterostructure

Cho drew on his TRW experience. ("That's why MBE systems all look like ion engines!") He designed an MBE apparatus with improved effusion cells for vaporizing the gallium and arsenic, vacuum pumps for removing the atmosphere and its impurities, and a shroud circulating liquid nitrogen to cool everything down to 77 K and so minimize thermal effects.

In addition, Cho wanted to see what occurred in the apparatus during the deposition, rather than just examining its output. So he outfitted the machine with a high-energy electron diffraction (HEED) equipment—thereby introducing *in situ* monitoring. "In situ monitoring is the key [to growing a single crystal] repeatedly. With it, I could actually watch the atoms migrate to their lattice sites."

Regarding the cross-fertilization between his early work at TRW and later developments in MBE crystal growth, Cho remarked: "It's so important for scientists to have a broad exposure to many technologies.

If you apply one technology to a second technology, you end up with a third technology."

FLEXIBLE RESEARCH STRATEGY. Watching Cho's progress in depositing uniform layers with MBE, and struggling himself to control layer thickness with LPE, Panish suggested that Cho "make a laser." But Cho, try as he might, could not control the apparatus well enough to make a laser that worked continuously at room temperature.

He finally figured out why. A semiconductor laser is a minority-carrier device: its successful operation depends on the presence of both electrons and holes (electron vacancies). Because these electrons and holes would "prefer" recombining at crystal defects to emitting light, the crystal has to be orders of magnitude more defect-free for a minority-carrier device than for a majority-carrier device.

"I realized I couldn't make material of high enough quality for minority-carrier devices, so I decided, 'let's make majority-carrier devices,'" Cho recalled. "As a scientist, you have to be flexible. When you see a dead-end street, you have to be able to change direction."

Accordingly, from 1972 through 1976, Cho systematically demonstrated MBE's performance by using the technique to create one majority-carrier device after another: a microwave GaAs voltage varactor (which changes capacitance in response to a change in voltage), an Impatt diode (which generates a very high frequency in response to a voltage), a mixer diode (which mixes two frequencies to produce a third), and a microwave field-effect transistor.

But in being used for majority-carrier devices, MBE was challenging another well-established technology: chemical vapor deposition (CVD). Like LPE, CVD deposited thick layers that were then chemically etched to the desired thinness. Cho demonstrated that with MBE the devices could be grown with layers of the exact thickness desired, without the need to etch.

LASER SUCCESS AT LAST. These triumphs notwithstanding, the majority-carrier devices were only one aspect of Cho's overall research strategy. "You have to plan your research work so that only some part of it is spent on very difficult problems," he observed. "The biggest trophies are the hardest to get. You also have to work on several moderately challenging problems and several easy ones. That way each year you have some productivity, so you can survive."

The big trophy that Cho was still hunting was the first MBE-grown room-temperature continuous-wave heterostructure laser with more predictable layer thicknesses than those attainable with LPE. In this work, Cho began to rely on the skills of GaAs-device specialist H. Craig Casey Jr., then a fellow member of Panish's technical staff (and now a professor of electrical engineering at Duke University in Durham, N.C.). "I began taking the material that Al grew and evaluating it so

he could determine how what he was doing in the growth affected the usefulness of the devices," Casey explained.

Cho worked in his laboratory day and night and on weekends. For months he documented the growth conditions in some 200 MBE runs, amounting to thousands of lasers. In each run, he altered the process to eliminate surface impurities, changed the temperature of the substrate on which the epitaxial layers were growing, and modified the thickness of the individual layers to create a device that had a sufficiently low laser threshold current density.

What was it like to work with such a dogged, single-minded colleague? "You really want to know?" Casey asked. "He was a pain in the ass! Now that he's mellowed over the years, he's a close friend. But back when we started this, we didn't know whether it would work or not. He gave attention to every detail and was so determined to make it work that he was suspicious of everything and everybody. We were fabricating the devices for him, and he couldn't believe they didn't work because they weren't grown right. He thought we were screwing up."

But Cho had a good reason for this close supervision. "Any time you want to break into a field against the grain of a well-established community, you have to do the experiment yourself so that you *know* what you're seeing. Sometimes the unexpected effects are the most exciting discoveries. If you just have technicians do the work and you do only the calculations, you miss a lot."

One result of Cho's direct involvement and eye for the unexpected was his observation that lasers made in the winter lased best, whereas those made in the summer did not work at all. "Then I realized that every time we opened the vacuum chamber, it would backfill with atmosphere and would have to be pumped down. In New Jersey's humid summer, that meant that water vapor was left in the chamber, whereas the winter air was dry."

To solve the problem, Cho equipped his MBE system with what he called a load lock. The invention operates like an air lock in a manned spacecraft: the sample is loaded not directly into the vacuum chamber, but into an intermediate one. The intermediate chamber is then evacuated before the inner vacuum chamber is opened to receive the sample. The load lock—another application of Cho's early career in space technology—is now standard on all MBE machines.

Cho's persistence paid off on Sept. 9, 1975. On that Tuesday, he finally achieved room-temperature continuous lasing from an MBE laser.

MBE TRIUMPHS. By this time, many investigators had begun to realize the value of MBE—not only for fabricating structures already built by LPE or CVD, but also for forming ones impossible to build any other way. Today MBE is a principal technique

used to build quantum-well devices, superlattices, and other structures composed of multiple ultrathin layers.

With the assistance of Deborah Sivco, a member of the technical staff, Cho's latest triumph with MBE has been to grow the indium-gallium-arsenide quantum cascade laser. The quantum cascade laser is fundamentally different from conventional semiconductor lasers. In the latter, the emission wavelength depends on the chemical composition of the active layer. In the new device, the emission wavelength can be changed by varying the thickness of the layers. In other words, simply by engineering the layer thicknesses, the *same material* can lase at a wavelength ranging from 4 to 10 μm !

Designed by Federico Capasso and Jerome Faist, two of Cho's colleagues at Bell Labs, the quantum cascade laser's structure was featured this year on the cover of the April 22 issue of *Science*. Growing the 540-layer quantum cascade laser took 3 hours—and the first one tested worked the first time. "That's so exciting because it means we really understand the physics!" Cho exclaimed.

REFLECTIONS ON A LIFE'S WORK. Intensely private about his personal life, Cho acknowledged that his dedication to his work always put time with his family at a premium. "Still, every evening I went home to eat dinner with them before going back to the office, and every morning we ate breakfast together." He and his wife and four children always spent Saturday evenings and Sunday together.

"I try the best I can to make our time together high quality, hopefully of the best quality to compensate for its length," he said. With pride, he pointed out that his daughter Brynna is studying nursing at William Patterson University in Wayne, N.J., while his son Derek and his other two daughters (Deidre and Wendy) are all at the University of Illinois, their parents' alma mater.

When John Arthur was asked how he felt seeing Cho develop MBE commercially and receive so much credit, he replied thoughtfully: "I have always been more concerned with my life outside of science—maintaining a family life. In other words, I really don't feel envious of him. He's chosen a hard road to travel and has earned everything he's got."

Cho is now at a reflective point in his career. Despite working exceptionally long hours, he feels guilty about not having enough time to do full justice to reading the technical literature, writing recommendations for promising young investigators, giving plenary talks, and doing all the hands-on research he would like to do.

"At one time I thought of changing fields. But there is so much still to do in MBE. Also, thousands of people might think, 'If Al Cho left, there must not be anything left in MBE,'" he ruminated. Still, he added, "Once I finish all my science, I want to get back to my art and photography." ■

Software reviews

PDEase's popularity predicted

Kenneth R. Foster

PDEase.

Macsysma Inc. Requires a PC based on the Intel 386/387 or 486DX (or equivalent) running DOS 5.0 or later. Requires 4-MB RAM, 4-MB hard-disk space (the program occupies 2 MB), EGA, VGA, or Super VGA graphics. May be run under Microsoft Windows, and produces Windows graphics, using the Macsysma Graphics Viewer. US \$499, with discounts for academic users. A limited student version (\$149) and a Sparc version for SunOS (\$999) are also available.



Field analysis programs calculate electric or magnetic fields around conductive or dielectric objects [see "Computing EM fields," *IEEE Spectrum*, November 1992, pp. 52-56]. An engineer would use one, for example, to calculate the capacitance of a microstrip line. Generally, though, the finite-element programs long available for such jobs are expensive and can be hard to adapt to novel problems.

PDEase is a breakthrough on two counts: flexibility and cost. Unlike other finite-element programs, PDEase accepts single partial differential equations, or systems of equations, directly from the user. The equations may be linear or nonlinear, or static or time-dependent, and can be of mixed elliptic-parabolic-hyperbolic type. As such they can represent a wide range of physical phenomena, including such topics as electric or magnetic fields, heat flow, diffusion, fluid flow, thermoelasticity, and stress/strain.

Hence PDEase's unprecedented flexibility. The user can easily solve problems involving coupled phenomena such as electric current and heat or thermoelasticity, for which other finite-element programs are not suited.

Note, too, that many competing products cost 10 times as much.

To use the program, the engineer prepares a batch file that specifies the equations, problem geometry, boundary conditions, quantities to be displayed, and other information. PDEase then interprets the equations, constructs a finite-element grid, and solves the problem repeatedly, with ever finer grids, until it achieves the desired accuracy.

The program will write its output to disk, or display the results in any of an assortment of plots by means of its excellent built-in graphics capabilities. PDEase can only handle two-dimensional problems or three-

dimensional ones where there is an axis of rotational symmetry. It can accept batch files written by Macsysma (a powerful computer algebra system also sold by the vendors) and it can use Macsysma's superb graphics program if a still higher quality of graphics output is needed.

I have used PDEase for several months in a variety of research projects. It was easy to learn, in part because of the 29 sample problems included with the 120-page loose-leaf manual. (Most of the problems are from mechanical engineering, though—the developers should add more for electrical engineers.) Writing the batch files and debugging them is straightforward but clumsy compared to more automated programs. The versions I tested (a beta-test version, and one of the earliest releases of PDEase) had some rough spots and minor bugs, but generally they worked well.

Flexibility has its costs, however. The most obvious is speed. In solving the same problem on a given system, PDEase is much slower and can handle fewer nodes than can Quick-Field, an efficient finite-element program for the PC [see "Quick and easy field analysis," *Spectrum*, December 1993, p. 64].

All the same, on my systems, one based on the Intel 80386 microprocessor running at 40 MHz and another using the Intel 80486 chip operating at 33 MHz, PDEase did well. It could easily handle models with tens of thousands of nodes, which probably is adequate for most problems. (The vendors have noticeably speeded up the latest release.) Writing the batch files takes some care since slight changes in the way a program is defined can greatly extend running time.

The user may need to brush up on physics and partial differential equations because PDEase is a tool that necessitates dealing explicitly with both. It is well worth the effort. PDEase is a fine product that deserves widespread popularity. **Contact:** Macsysma Inc., 20 Academy St., Arlington, MA 02174-6436; 617-646-4550; fax, 617-646-3161; e-mail, info-macsysma@macsysma.com; or circle 100.

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Statistics on Windows

Alfred Riddle

In the business of selling statistical software since 1960, BMDP Statistical Software has products ranging from the comprehensive Classic Release 7.0 to diverse task-oriented

products. Its New System product is the company's first step to building a statistical system within the Windows user interface.

The package provides an integrated Windows environment for basic statistical analysis and visualization. It offers six plots and four analysis modes, most of which interact to give the user tremendous flexibility and a short learning curve.

The plots, which are all two-dimensional, include scatter and box plots, histograms, and bar charts, as well as normal probability and means comparisons. The analysis modes include descriptive statistics, regression, tests, and analysis of variance (Anova), which determines how much of a variance is experimental error and how

BMDP New System for Windows: Version 1.0.

BMDP Statistical Software Inc. Requires IBM PC-compatible having at least 4-MB RAM, 6-MB hard-disk space, Windows 3.1, and small fonts. US \$395; student version, \$59.95.



much is a valid result.

New System minimizes the effort of analyzing data. The user can easily manipulate plots and readily modify analyses without returning to the initial spreadsheet window. Although visualization is not a large part of this program, the plot routines contained many visual aids. Even the plot colors and patterns were easily customized. In short, the program feels well balanced and useful. Moreover, BMDP is planning to expand New System to a level comparable with its Classic product.

I used New System as many new buyers would. I opened up the box, read the instructions, and began to use the software. The only installation problem I had was that the setup program could not find my autoexec file since I installed the software on the D drive. Once inside the program, I loaded an ASCII file and tested the various features. New System can read all the major spreadsheet, statistical software, and database file formats.

The ASCII file import worked flawlessly on my space-delimited file. A dialog box allows the user to set other delimiters. All the features worked as advertised, and I did not find any bugs. A Transform menu is filled with basic mathematical operations, but the user-equation dialog was more useful to me. I found BMDP's technical staff to be very helpful, as long as I provided them

(Continued on p. 75)

Employment opportunities

Organizations seeking engineers and scientists describe their various openings in the following advertising section

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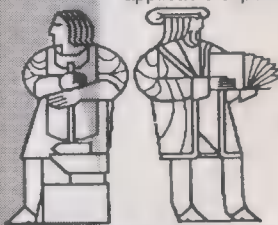
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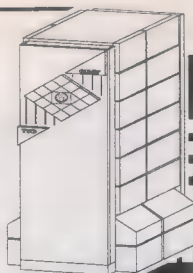
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MATHEMATICS
MECHANICAL ENGINEERING
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Specific information regarding the fellowship and an application package are available from Battelle Memorial Institute, a not-for-profit research institution, which is administering the program for the Department of Defense.

To request a copy of the application materials to be mailed directly to you, contact Battelle at the following address:

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Completed applications must be received by Battelle by January 18, 1995.

Recent Books

(Continued from p. 18T2)

Energy Storage for Power Systems. Ter-Gazarian, A., IEE/INSPEC, Piscataway, N.J., 1994, 232 pp., \$95.

Cyberspace and the Law: Your Rights and Duties in the On-line World. Cavazos, Edward A., and Morin, Gavino, MIT Press, Cambridge, Mass., 1994, 230 pp., \$19.95.

Microsoft EXCEL 5 For the Macintosh Step

by Step. Catapult, Inc., Microsoft Press, Redmond, Wash., 1994, 368 pp., \$29.95.

Xlib by Example. Yang, Cui-Qing, and Ali, Mahir S., Academic Press, New York, 1994, 635 pp., \$39.95.

Encyclopedia of Applied Physics, Vol. 9: Magnetic Materials to Mechanical Vibration and Damping. Eds. Trigg, George L., et al., VCH Publishers, New York, 1994, 600 pp., \$295 (hardcover), \$235 (standing order).

Designing Engineers. Bucciarelli, Louis L.,

MIT Press, Cambridge, Mass., 1994, 256 pp., \$24.95.

Monte Carlo Simulation of Semiconductor Devices. Mogilestue, C., Chapman & Hall, New York, 1993, 326 pp., \$99.95.

Introduction to Control Theory, 2nd edition. Jacobs, O.L.R., Oxford University Press, New York, 1993, 390 pp., \$33.95.

Fractal Cities. Batty, Michael, and Longley, Paul, Academic Press, New York, 1994, 394 pp., \$35.

The Benchmarking Book. Spendolini, Michael J., Amacom, New York, 1994, 209 pp., \$17.95.

Inside Visual C++ , 2nd edition, Version 1.5. Kruglinski, David J., Microsoft Press, Redmond, Wash., 1994, 768 pp., \$39.95.

Robust Industrial Control: Optimal Design Approach for Polynomial Systems. Grimbale, Michael J., Prentice Hall, Englewood Cliffs, N.J., 1994, 597 pp., \$80.

Semiconductor Ceramics: Grain Boundary Effects. Hozer, Leszek, Prentice Hall, Englewood Cliffs, N.J., 1994, 200 pp., \$59.95.

The Quest for Life in Amber. Poinar, George, and Poinar, Roberta, Addison-Wesley, New York, 1994, 240 pp., \$25.

The Perfect Machine: Building the Palomar Telescope. Florence, Ronald, HarperCollins, New York, 1994, 451 pp., \$27.50.

Prime Time Freeware for AI, Issue 1-1. Ed. Kantrowitz, Mark, Prime Time Freeware, Sunnyvale, Calif., 1994, 220 pp., \$60.

Genetic Programming II: Automatic Discovery of Reusable Programs. Koza, John R., MIT Press, Cambridge, Mass., 1994, 746 pp., \$45.

Distributed Operating Systems. Tanenbaum, Andrew S., Prentice Hall, Englewood Cliffs, N.J., scheduled for 1995 release, 614 pp., \$57.

1995 EEM/Electronic Engineers Master, Vol. A: Electronic Components; Vol. B: Electromechanical, Electro-Optical, and Military Components; Vol. C: Interconnections, Packaging, and Hardware; Vol. D: Power Sources, Instrumentation, Computer Products, and Equipment. Hearst Business Publishing/UTP Division, Garden City, N.Y., 1995 release, 4000 pp., \$99 (annual subscription).

High Voltage Engineering and Testing. Ed. Ryan, H.M., IEE/INSPEC, Piscataway, N.J., 1994, 447 pp., \$95.

Guide to Writing DCE Applications, 2nd edition. Shirley, John, et al., O'Reilly & Associates, Sebastopol, Calif., 1994, 440 pp., \$29.95.

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SP1094

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Calendar

(Continued from p. 18E10)

Multi-Chip Module Conference—MCMC-95 (C, CAS, et al.); Jan. 31–Feb. 2; Cocoanut Grove, Santa Cruz, Calif.; Lisa Pascal, Computer Engineering, University of California, Santa Cruz, CA 95064; 408-459-2263; fax, 408-459-4829; e-mail, lisa@cse.ucsc.edu.

FEBRUARY

16th Aerospace Applications Conference (AES); Feb. 4–11; Snowmass Village Conference Center, Aspen, Colo.; Sohrab Mobasser, Jet Propulsion Lab, MS 198–235, 4800 Oak Grove Dr., Pasadena, CA 91109; 818-354-4466; e-mail, Sohrab_Mobasser@ccmail.JPL.Nasa.Gov.

11th Semiconductor Thermal Measurement and Management Symposium—Semitherm XI (CPMT); Feb. 7–9; Red Lion Inn, San Jose, Calif.; Vincent P. Manno, Department of Mechanical Engineering, Tufts University, Medford, MA 02155; 617-628-5000, ext. 2548; fax, 617-627-3819; e-mail, vmanno@pearl.tufts.edu.

International Solid-State Circuits Conference—ISSCC '95 (SSC, et al.); Feb. 15–17; San Francisco Marriott Hotel; Diane S. Suiter, Courtesy Associates Inc., 655 15th Street., N.W., Suite 300, Washington, DC 20005; 202-639-4255; fax, -347-6109.

International Topical Symposium on Technologies for Wireless Applications (MTT); Feb. 21–23; Vancouver Trade and Convention Center, B.C., Canada; Peter W. Staecker, M/A-Com Inc., 100 Chelmsford Street, Lowell, MA 01853-3294; 508-656-2607; e-mail, p.staecker@ieee.org; fax, 508-656-2777.

MARCH

11th International Zurich Symposium and Technical Exhibition on Electromagnetic Compatibility (EMC, et al.); March 7–9; Swiss Federal Institute of Technology, Zurich, Switzerland; Secretariat, IKT, ETH, Zentrum, CH-8092, Zurich, Switzerland; (41+1) 256 2788; fax, (41+1) 262 0943.

Southcon '95 (Region 3, Florida C); March 7–9; Greater Fort Lauderdale/ Broward County Convention Center, Florida; J. Carlisle, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045; 800-877-2668; fax, 310-641-5117.

National Radio Science Conference (ED); March 21–23; Alexandria University,

Egypt; Ibrahim A. Salem, 17 Elqouba St./3, Roxy Heliopolis, Cairo-11341, Egypt; (20+2) 258 0256; fax, (20+2) 349 8217.

International Conference on Micro-electronic Test Structures (ED); March 23–25; New Public Hall, Nara, Japan; Loren W. Linholm, National Institute of Standards and Technology, B-360 Technical Building, Gaithersburg, MD 20899; 301-975-2052; fax, 948-4081; e-mail, linholm@sed.eeel.nist.gov.

Fourth International Workshop on Responsive Computer Systems (CS); March

29–31; Hotel President, Berlin; Volker Tschammer, GMD-Fokus, Hardenbergplatz 2, D-10623 Berlin, Germany; (49+30) 254 99 226; fax, (49+30) 254 99 202; e-mail, tschammer@fokus.berlin.gmd.d400.de.

APRIL

Southeastcon '95 (Region 3, East NC); April 2–5; Sheraton Imperial Hotel & Convention Center, Research Triangle Park, N.C.; Charles J. Lord, 108 Huntington Circle, Cary, NC 27513; 919-781-8148.

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Nominations and letters of interest should be sent to: Dr. Victor L. Lechtenberg, Chairman; Engineering Dean Search Advisory Committee; 1140 AGAD, Purdue University; West Lafayette, IN 47907-1140. Screening of applications will commence October 15, 1994, and continue until the position is filled.

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Software reviews

(Continued from p. 74)

with my license number first.

The manual has four parts: a tutorial, a detailed description, a set of statistical definitions, and a set of examples. It is well formatted and easy to read.

I did, however, find a few rough spots in New System. The first occurred in the variable selection dialog box. The user is provided with several text boxes for various analysis and plotting functions, along with a list of column names to place in the boxes. Nonetheless, although the cursor changes to a text bar, it is impossible to type in any of the text boxes. Instead, it is necessary to click on the column names and drag them from the list to the text boxes. Of course, the user rapidly adjusts to all this dragging and dropping.

Second, when an ASCII file is being imported, New System will present a message stating that it cannot understand the file format. After the user clicks OK, it will go on to present a dialog box with a list of formats to choose from. On several occasions I thought I had been stopped by a problem, and went on to find there was none.

In summary, New System is easy to use and works well. It does not work as intuitively as some statistical programs I have used, but then this is version 1.0.

If New System's feature set satisfies your requirements, you will find it an enjoyable program. *Contact: Bill Sanders, BMDP Statistical Software Inc., 1440 Sepulveda Blvd., Suite 316, Los Angeles, CA 90025; 310-207-8800, ext. 312; or circle 101.*

Alfred Riddle is the principal at Macallan Consulting, Milpitas, Calif. He can be reached at 408-262-3575 (telephone and fax); e-mail, alfy@cup.portal.com.

Recent software

CADDS 5, Revision 5. For product modeling from design through manufacturing. Includes new associativity, mock-up support, and design optimization tools. Now supports Digital Equipment's Alpha AXP, Silicon Graphics' R4000/R4400 series, Sun's Sparc, and Hewlett-Packard's Apollo 9000 Series 700. US \$3200 and up. *Contact: Computervision Corp., 100 Crosby Dr., Bedford, MA 01730-1480; 617-275-1800; fax, 617-275-2670; or circle 102.*

ABC ToolKit. For visualizing workflow and for documenting, analyzing, measuring, and improving performance. Runs on computers using Windows 3.1 or higher. US \$895. *Contact: Micrograx Inc., 1303 East Arapaho, Richardson, TX 75081; 800-676-3110; fax, 214-994-6334; or circle 103.*

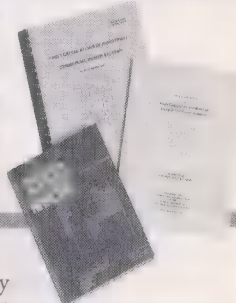
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EEs' tools & toys

Data-acquisition board interfaces with Matlab

The trouble with solving a problem by combining products from two or more vendors is, in a word, incompatibility. For example, one could save much of the cost of a stand-alone Fourier analyzer by using the popular numerical math Matlab package to control a data-acquisition box and analyze the data it acquires. But first one would have to toil away at writing the necessary virtual instrument interfaces in Matlab code.

Or would one?

Certainly not if the job had been done already, and if the software were bundled with the hardware at an attractive price. That's what DSP Technology Inc. has produced in its SigLab 20-22, a data-acquisition and signal-analysis system for which the company has developed a total of six virtual instrument interfaces written in Matlab code.

The hardware is a two-channel audio-frequency data-acquisition system with band-



The SigLab-Matlab combination is being applied here in its system-identification mode to the job of measuring and computing a z-plane model of the head-positioning system in a disk drive. The task has been considerably simplified because the stimulus generation, the data acquisition, and the z-plane modeling have all been integrated into a single package. The hard-disk drive under test is shown at the left, sitting on top of the SigLab box.

widths selectable from 2 Hz to 20 kHz. It includes fixed analog and programmable digital filters that provide more than 80 dB of antialiasing protection, and its 16-bit delta-sigma analog-to-digital converters can run at up to 51.2 kilosamples per second.

The software emulates six instruments: an oscilloscope; spectrum, network, and swept sine analyzers; a function generator; and a lattice system identifier. When the user selects one of the instruments within the Matlab environment, the software presents a graphic display of the instrument, complete with control buttons, pick lists, and sliders. Those graphics objects control both how the instrument makes measurements and how it processes the data it acquires.

The SigLab box has the same footprint as a sheet of standard notepaper—216 by 280 mm—and is a mere 51 mm thick. It weighs 2.0 kg. Its internal nickel-cadmium

battery powers it for up to three hours.

The standard system sells for less than US \$5000. It is available from stock. *Contact: DSP Technology Inc., 48500 Kato Rd., Fremont, CA 94538-7385; 510-657-7555; fax, 510-657-7576; or circle 106.*

INSTRUMENTATION

Measurements mixed to taste

One of the most frustrating aspects of designing modern test and measuring instruments is that—thanks to advances in integrated circuits—features are all too often easier to add than to link up with the user. Sometimes the feature is inconvenient to invoke, requiring many actions of the user. At other times, worse yet, the user doesn't realize that the feature exists.

Fluke Corp.'s answer to both problems, as embodied in its ScopeMeter Series II test tool, is to combine a one-button Measure Menu with a Continuous Autoset function. The first of these automatically configures the instrument for any of 30 measurement tasks, while the second automatically makes whatever attenuator, timebase, and other changes are needed as the user probes different test points or as the input signal varies.

Basically, the ScopeMeter is a handheld instrument combining the functions of a 3-2/3-digit (3000-count) true-rms digital multimeter (DMM) and a 50-MHz digital storage oscilloscope. It has a maximum sampling rate of 25 megasamples per second, which means that the scope's full 50-MHz analog input bandwidth is useful only for repetitive signals. For events of

this sort, the scope has a timing resolution of 400 ps. For single-shot events, the highest frequency that can be successfully displayed is somewhere in the vicinity of 5 MHz.

The new ScopeMeter differs from some combination instruments in that it does not simply pack two separate tools into one toolbox, but sometimes has them work together.

For example, all ScopeMeter DMM readings are accompanied by a picture of the waveform being measured. Asymmetries, noise, glitches, and other anomalies may be viewed along with DMM readings, so that the user has a much better sense of how the unit under test is operating, and what problems it might be experiencing.

The unit can also boast some valuable new data-recording features. Its TrendPlot function graphs the minimum, maximum, and average readings of a signal over intervals of 2 minutes to 30 days. An envelope mode provides a record of all of the changes to the waveform. With the Series II's ability to time-stamp waveforms and to show new highs and lows as they occur, the user is well equipped to understand (and even recreate) the conditions under which unusual events occur.

The instrument runs off a rechargeable nickel-cadmium battery, which can typically power it for four hours at one go. (The running time varies wildly, being heavily dependent on the use made of the display

screen's electroluminescent backlight.) When necessary, the ScopeMeter may also be run off four alkaline C cells.

The ScopeMeter Series II is actually four products. At the top of the line is the Model 99, a dual-channel instrument capable of storing 10 screens, 20 waveforms, and 40 set-ups. It has a standard repertoire of 18 meter measurements and 15 scope cursor measurements. In addition, it can perform waveform mathematics, and has a built-in signal generator. With optional software, it may be fully controlled by means of a host computer through its serial port. It has a price of \$2195.

The Model 96 is similar, with three exceptions: it stores only 5 screens, 10 waveforms, and 20 set-ups; it can use a host computer only as a printer; and it has no signal generation or waveform mathematics capabilities. It sells for \$1895.

The Model 92, in turn, is like the Model 96 except that it has none of the latter's memories, cannot make cursor measurements, and simply sends its screens to a host personal computer. Its price is \$1595.

Fourth and finally, the Model 91 is a one-channel version of the Model 92. It sells for just \$1295.

All four units are available from Fluke distributors worldwide. *Contact: Fluke Corp., Box 9090, Everett, WA 98206-9090; 206-356-5500; toll-free, 800-44-Fluke (800-443-5853); in Europe, Fluke Europe*

Tools & toys

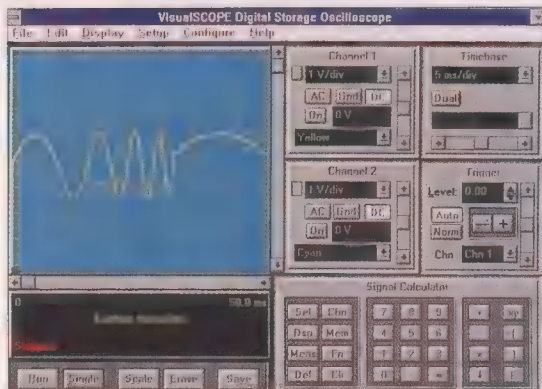
B.V., Box 1186, Eindhoven, the Netherlands; (31+40) 644-200; fax, (31+40) 644-222; or circle 107.

PC-based scope works with Windows

Keithley MetraByte's PCIP-Scope—a plug-in board and software combination for turning an IBM-type personal computer into an oscilloscope—is now available in a version that runs under Microsoft Windows. This not only gives the virtual instrument a familiar-looking user interface, but it also simplifies the business of importing or exporting data from or to other Windows applications.

The two-channel scope has a maximum real-time sampling rate of 20 megasamples per second; however, for repetitive signals, an interlaced sampling mode allows an equivalent sampling rate of 500 megasamples per second. The scope has an analog input bandwidth of 10 MHz. Its 2048-sample memory may be allocated to one channel or split between the two.

VisualScope for Windows, the product's new software portion, lets the user display up to four signals simultaneously. In particu-



The Windows version of Keithley MetraByte's PCIP-Scope turns an IBM-type personal computer into a digital oscilloscope with a sampling rate of 20 megasamples per second. Its user interface looks a lot like the front panel of a traditional bench-top oscilloscope.

lar, it allows previously saved or calculated waveforms to be compared with live inputs. Cursors let the user measure time intervals, amplitudes, and frequencies directly.

Dual timebase windowing makes it easy to zoom in on a desired segment of a waveform. All told, the scope can automatically make 14 measurements, including root-mean-square values, rise and fall times, and

duty cycles. In addition, of course, users may employ its built-in signal calculator to make many other measurements and computations.

The PCIP-Scope is priced at \$1199. A software upgrade for previous releases of the scope sells for \$99. The product is available from stock. *Contact: Keithley MetraByte, 440 Myles Standish Blvd., Taunton, MA 02780; 800-348-0033; or circle 108.*

NEW AND NOTeworthy

- To help test-engineers promote boundary-scan test strategies within their companies, Alpine Image Systems Inc., Mountain View, Calif., has updated its ChampionChip List, a compilation of commercially available parts that comply with the IEEE 1149.1 boundary-scan specification. The list covers a total of 224 parts from 59 vendors. For a free copy, call Ellis Goldberg at 415-941-3247, or fax him at 415-941-7642, or circle 109.

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Academic Positions Open

Hong Kong University of Science and Technology: Department of Electrical & Electronic Engineering invites application for tenure-track faculty positions for all ranks (Professor, Reader, Senior Lecturer and Lecturer) for openings starting in January and July 1995. The EEE Department at HKUST was established in 1991 and offers BEng. in Electronic Engineering and MSc., MPhil. and Ph.D in Electrical and Electronic Engineering. The Department currently has over 500 undergraduate students and 120 postgraduate students with about 40 full time faculty members and 40 support staff. We are expecting to have 10 new faculty openings in 1995 to allow the Department to grow to 50 full time faculty members. The Department is planning to reach a full size of 65 full time faculty members by 1998 with more than 100 support and research staff. The Department has major research interests in Integrated Circuits Design; Microelectronics; Photonics; Sensors and Instrumentation Systems; Communications and Control; Circuits, Signals and Systems; Robotics and CAD/CAM; Computer Engineering and Bioengineering. We are particularly interested in qualified applicants with relevant teaching and research experience in VLSI Circuits Design and Tests, Microelectronics Devices and Technology, Photonics, Optoelectronics, Microwave Electronics, Microsensors and Micromachines, Biomedical Sensors and Bioinstrumentation, Circuits and Systems Theory, Signal Processing, Wireless Communications, Video Technology, Robotics and Control. We are also interested in applicants with expertise in Computer Architecture, Computer Hardware Design and Computer Networking for our Computer Engineering Programme. Applicants should have a PhD with demonstrable experience in teaching and research. We are particularly interested in applicants in the areas of microelectronics, communications, networking and computer engineering for senior faculty openings. The Department has excellent facilities for teaching and research with 20 modern teaching and research laboratories. The University has central research facilities including a complete Microelectronics Fabrication Centre (MFC) and a well-equipped Material Preparation and Characterization Centre (MCPC). All formal instructions are given in English. Salary ranges are from USD 48,400 to USD 80,800 per annum for Lecturer; USD 75,100 to USD 104,100 per annum for Senior Lecturer and Reader; and a

minimum of USD 107,300 per annum for Professor in 1993-4. Salaries in 1994-5 are expected to increase by approximately 9%. General fringe benefits including medical and dental benefits, annual leave, and children's education allowances are provided. Air passages and housing are also provided where applicable. Initial appointments will generally be on three-year contract terms; ■ gratuity of 25% of the total basic salary drawn will be payable upon successful completion of contract. Re-appointment after the initial contract will be subject to mutual agreement. Applications including full curriculum vitae, list of publication, and names, addresses and phone numbers of at least five references should be directed to: Professor Peter Cheung, Head, Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong. Applications will be considered until all the positions are filled.

Washington State University at Tri-Cities, School of Electrical Engineering and Computer Science: One faculty position at the Assistant or Associate Professor level is available starting at the beginning of the 1995-96 academic year, sited at WSU Tri-Cities in Richland, WA. A PhD in electrical engineering or a closely related field is required. The successful candidate will contribute to instruction at the undergraduate and graduate levels in electrical engineering and maintain an active research program. Areas of research interest include power, computer engineering, the non-destructive testing of materials, and electromagnetic field theory. Industrial experience is desirable. Applicants should provide a resume and a list of three references including addresses, phone numbers and the rank they are applying for. First deadline for applications is October 30, 1994 but applications will be entertained until position is filled. Address correspondence: Chair, Search Committee EECS, WSU Tri-Cities, 100 Sprout Road, Richland, WA 99352. WSU is an EO/AA educator and employer. Protected group members are encouraged to apply.

Chair in Photonic Systems: The Department of Electrical Engineering of McGill University is seeking an incumbent for its Chair in Photonics Systems. This Chair is funded by Bell Northern Research and Northern Telecom Ltd, McGill University and the Natural Sciences and Engineering Research Council (NSERC) of Canada through their Industrial Research Chair (IRC) program. The successful candidate must be an internationally recognized authority, preferably working at the interface between photonic devices and systems, with outstanding scientific and leadership qualities that can maintain the Department of Electrical Engineering at the forefront of research in Photonic Systems. An important condition for achieving this goal is the appointee's ability to strengthen our academic programs for both graduate and undergraduate students. The position carries a highly competitive salary, junior faculty positions specifically designated in Photonics systems, necessary laboratory space and, above all, strong University support for the above stated goals. Enquiries including an updated Curriculum Vitae and the names of at least three references should be sent to Professor Nicholas C. Rumin, Chairman, Department of Electrical Engineering, McGill University, 3480 University Street, Montreal, Quebec, H3A 2A7, Canada. In accordance with Canadian Immigration requirements, this advertisement is directed to Canadian citizens and permanent residents of Canada. McGill University is committed to equity in employment.

Chair, Department of Electrical Engineering: The University of Missouri-Rolla (UMR) is seeking an outstanding individual to fill the position of Chair, Department of Electrical Engineering. Rolla is located in the Ozarks region of South Central Missouri, approximately 100 miles southwest of St. Louis. UMR is one campus of the four-campus University of Missouri System and has as its major emphasis undergraduate and graduate education in engi-

neering and science. The Department offers B.S., M.S., and Ph.D. degrees with emphasis in all major areas of electrical engineering. Candidates should have an earned doctorate in electrical engineering or ■ closely related field and should have an established reputation in both educational and research activities. The Chair will be responsible for the continued development of the faculty, the undergraduate and graduate programs, and the research activities within the Department. Applications, including ■ resume and list of three references, and nominations for this position should be sent to: Dr. Paul Stigall, EE Search Committee Chair, Room 101 ERL, University of Missouri-Rolla, Rolla, MO 65401. The deadline for receipt of applications is November 15, 1994. UMR is an equal opportunity/affirmative action employer.

Lehigh University: The Department of Electrical Engineering and Computer Science seeks applicants for ■ tenure-track faculty position. Candidates must have a PhD in computer engineering, computer science, or electrical engineering. We require a strong commitment to teaching and evidence of innovative research through appropriate journal publications. Preferred areas include: computer architecture, manufacturing applications, networking, optoelectronics, and software systems. We offer programs in computer engineering, computer science and electrical engineering leading to a PhD degree. Lehigh University is an affirmative action/equal opportunity employer. Women and minorities are encouraged to apply. Please send vita and names of at least three references to Dr. Alastair McAulay, Faculty Search Committee, Department of Electrical Engineering and Computer Science, Lehigh University, 19 Memorial Drive West, Bethlehem, PA 18015.

Chair, Department of Electrical Engineering: The University of Texas at Arlington invites applications for the position of Chairperson, Department of Electrical Engineering. Duties will assume in summer or fall of 1995. Candidates should hold an earned doctorate in Electrical Engineering, have ■ commitment to educational programs at both the undergraduate and graduate levels, and be recognized as a leader in research and education. The Chairperson will provide leadership in the ongoing growth of the department, including fostering strong relationships with government agencies and the extensive Dallas/Ft. Worth industry. UTA has 23,000 students and the largest College of Engineering in north Texas. The EE Department is situated in a new building and has 30 full time faculty, 500 undergraduate students, 300 masters students, and 100 Ph.D. students. Facilities include 67,000 sq. ft. of research and educational laboratories in: the NSF Industry/University Center for Electronic Materials, Devices and Systems, the Wave Scattering and Remote Sensing Research Center, the Energy Systems Research Center, the Human Systems and Performance Institute, the Medical Imaging Laboratory, the Applied Physical Electronics Center, the Electro-Optics Laboratory, and Telecommunications and Signal/Image Processing Laboratories. UTA's Automation and Robotics Research Institute provides 48,000 sq. ft. of additional facilities for interdisciplinary R&D in manufacturing, robotics, and controls. The EE Department has significant external funding from NSF, DoD, ARPA, and other government agencies, as well as from local Dallas/Fort Worth industry. A complete resume and the names of five references should be sent to: Professor Don Wilson, EE Chairman Search Committee, Box 19016, The University of Texas at Arlington, Arlington, Texas 76019. Tel. 817-273-2603, fax. 817-794-5010, email wilson@mecad.uta.edu. UTA is an affirmative action equal opportunity employer.

The University of Cincinnati, Electrical and Computer Engineering Department. Applications are solicited for ■ tenure track Assistant Professor faculty position in the Department of Electrical and Computer Engineering starting January, 1995. The prospective faculty member should have an earned Ph.D. in Electrical

Engineering. S/He is expected to develop a research program with external funding and documented scholarship and to collaborate with established research programs in the area of millimeter-wave and photonic devices, circuits and systems. Applicants with expertise in epitaxial growth (particularly MOCVD) of III-V semiconductors will be preferred. An Aixtron Model 200 reactor and associated state-of-the-art x-ray and photoluminescence characterization facilities are available. The Department offers MS/Ph.D. programs in electrical engineering, computer engineering, and computing sciences as well as an ABET fully-accredited undergraduate program in Electrical and Computer Engineering. The Department has 30 full-time faculty, 200 full-time graduate students, 400 undergraduate students. Curriculum vitae and the names of four references should be sent to: Prof. Peter B. Kosel, Interim Head, Electrical and Computer Engineering Department, P.O. Box 210030, University of Cincinnati, Cincinnati, Ohio 45221-0030. The University of Cincinnati is an Affirmative Action/Equal Opportunity employer and encourages and welcomes applications from women and minorities.

Faculty Positions available in Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, Michigan: Applications are solicited for faculty positions in the computer science and engineering division at all ranks. Qualifications include an outstanding academic record, significant involvement in research, a doctorate or equivalent in electrical engineering, computer engineering, or computer science, and a strong commitment to teaching and research. Particular areas of interest include: Multimedia, high-performance computer networks, software for distributed systems and compiler-based computer architecture. Please send resume and names of five references to: Professor Toby J. Teorey, Chair of the Faculty Search Committee, CSE Division, Department of Electrical Engineering & Computer Science, The University of Michigan, 1301 Beal Avenue, Room 3401, Ann Arbor, MI 48109-2122. An Equal Opportunity/Affirmative Action Employer.

Faculty Positions available in Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, Michigan: Applications are solicited for faculty positions in Electrical Engineering and Computer Science at all ranks. Qualifications include an outstanding academic record, significant involvement in research, a doctorate or equivalent in electrical engineering, computer engineering, or computer science, and a strong commitment to teaching and research. Particular areas of interest include: Solid-state electronics and manufacturing; signal processing; ultrafast optics and high intensity laser interaction with solids; display technology; multimedia, high-performance communication networks; software; distributed systems and computer architecture. Please send resume and names of five references to: Professor George I. Haddad, Chair, Department of Electrical Engineering & Computer Science, 1301 Beal Avenue, Room 3303, The University of Michigan, Ann Arbor, MI 48109-2122. An Equal Opportunity/Affirmative Action Employer.

The Department of Electrical and Computer Engineering, The University of Texas at Austin, invites applications for tenure-track positions at the assistant professor level, in the area of computer engineering. Applicants must demonstrate exceptional teaching ability and research potential. Excellent English communication skills are required. Applicants, who do not hold a Ph.D., must be making satisfactory progress toward a Ph.D. or equivalent in electrical engineering, computer engineering or a related area, with a reasonable expectation of completion by August 31, 1995. Successful candidates are expected to pursue an active research program, perform both undergraduate and graduate teaching, and supervise graduate students. Priority will be given to applications received by February 1, 1995. Send letter of application, vita and a list of addresses for at least three references to the following address: Dr. Stephen A. Szygenda, Chairman, Department of Electrical and Computer Engineering, The University of Texas at Austin is an Equal Opportunity/Affirmative Action Employer.

Department Chair, Electrical and Computer Engineering, West Virginia University: Nominations and applications for the position of Chairperson are invited. Preference will be given to applications for the position of Chairperson are invited. Preference will be given to applications received by January 31, 1995. The search will continue until the position is filled. Candidates must have a Ph.D. in Electrical or Computer Engineering or a related discipline and should demonstrate excellence in teaching, research and ongoing scholarly activities which qualify the individual for full professor position. The chairperson is expected to provide leadership and vision for the department and should communicate effectively with alumni, faculty, other chairs and higher administration within the university. The chairperson should take an active role in faculty development and work closely with the faculty to promote quality teaching and research. The Department offers ABET accredited BS, degrees and M.S. and Ph.D. degrees in Electrical and Computer Engineering. It has 17 faculty members, 250 undergraduate students and 80 graduate students. West Virginia University is the State's only comprehensive land grant, doctoral granting university with an enrollment of 23,000 students. The University is at the center of a developing high technology corridor. The department is playing a major leadership role in its development. Several federal research facilities are located nearby. Morgantown is a scenic, diverse community of 45,000 situated 70 miles south of Pittsburgh, PA. Applications should include a letter of interest, resume, and the names of three references. Women and minorities are encouraged to apply. Send applications and nominations to: Dr. Ralph W. Plummer, Chair of the ECE Chair Search Committee, P.O. Box 6107, West Virginia University, Morgantown WV 26506-6107. For additional information, telephone (304) 293-5131 ext 716 or send email to: chair_search@ece.wvu.edu West Virginia University is an equal opportunity affirmative action institution.

Post Doc: microfabrication of polymer actuators. Contact E. Smela: smela@ifm.liu.se; fax +46 13 137568; Applied Physics Dept., Linköping Univ., 58183 Linköping, Sweden.

Assistant/Associate Professor: The Applied Science Department of the University of Arkansas at Little Rock (UALR) invites applications for a full-time tenure track faculty position at the Assistant/Associate Professor level. A Doctorate in Electrical Engineering or related field is required. The position will be filled as early as January 1, 1995. The Department is an interdisciplinary graduate level only program offering the M.S. and Ph.D. degrees. The Department emphasizes applied research in optics, electronics and signal processing and their applications to the measurement and control field. The successful candidate will have experience in one or more of the following areas: signal processing, microprocessor applications, instrumentation, or analog and digital communications. He/She will be expected to teach and develop graduate courses, supervise graduate students, and establish independent sponsored research programs. Industrial experience is desirable. Apply with a letter stating professional objectives, resume, and the names of three references to Dr. Emil C. Muly, Chair, Department of Applied Sciences, The University of Arkansas at Little Rock, ETAS 575, 2801 South University, Little Rock, AR 72204-1099. The University of Arkansas at Little Rock is an equal opportunity affirmative action employer and actively seeks the candidacy of minorities, women, Vietnam era veterans and persons with disabilities. Under Arkansas law, all applications are subject to disclosure.

University of Notre Dame, Electrical Engineering: The Department of Electrical Engineering has an open junior (tenure track) faculty position in the general area of Communication Systems. Specific areas include, but are not limited to, wireless, video, multimedia, and secure communication. Applicants should have a Ph.D. in Electrical Engineering or a related field. The Department offers B.S., M.S., and Ph.D. programs in Electrical Engineering and has 150 undergraduate students, 75 full time graduate

students, and 22 faculty. Active research programs exist in two broad areas: Electronic Circuits and Systems and Electronic Materials and Devices. Applicants should have interest in teaching at the undergraduate and graduate levels, advising students, and conducting research. Rank and salary are negotiable. Interested persons should submit a complete resume and names of three references to: Dr. Daniel J. Costello, Chairman, Department of Electrical Engineering, University of Notre Dame, Notre Dame, Indiana 46556. The University of Notre Dame is an Affirmative Action/Equal Opportunity Employer.

The University of Nevada, Reno invites applications and nominations for the position of Dean of Engineering. A comprehensive, land-grant institution, the University has an enrollment of approximately 8,600 undergraduate students and 3,000 graduate students in 9 colleges and schools. Within the College are Departments of Civil Engineering, Computer Sciences, Electrical Engineering and Mechanical Engineering. Approximately 900 undergraduate and 300 graduate students are currently enrolled in the College's programs. Faculty and students also participate in multidisciplinary programs such as hydrology and environmental engineering. The College has built new facilities in the past three years and has also added the University's computer science program. With these additions and with a talented faculty it is expected that the College will play a significant role in the diversification of Nevada's economy that takes place over the next ten years. The Dean is the chief academic and administrative officer of the College and reports to the Vice President for Academic Affairs. The successful candidate must: have an earned doctorate and a record of teaching, scholarship, research and service appropriate for a tenured full professor in one of the College's departments, have proven leadership skills and significant administrative experience in education, industry, or government, with line authority for personnel and budget. Preference will be given to candidates who: demonstrate the ability to develop a strategic vision through planning; enhance diversity of student body and faculty; communicate effectively with faculty, students, business leaders and the public; raise funds in support of the College's educational and research missions and strengthen ties with College stakeholders. Persons interested in being considered for the position, or who know of qualified individuals who should be considered, please write or call the Chair of the Search Committee: Dr. James L. Hendrix, Dean's Office, College of Engineering, University of Nevada, Reno, Mail Stop 256, Reno, Nevada 89557. Professor Hendrix can be reached at (702) 784-6925 or 6987; faxes should be sent to (702) 784-4466. Applicants should include a letter of application, a curriculum vitae and the names and telephone numbers of 5 references. The letter of application should include a description of the candidate's administrative style and comments relative to a college of engineering's role within a land-grant university. Review of applications will begin November 15, 1994. Applications will be accepted until the position is filled. It is anticipated the successful candidate will be able to assume the position July 1, 1995. The University of Nevada, Reno is an affirmative action/equal opportunity employer.

Announcement: Electrical and Systems Engineering (ESE): Oakland University (O.U.) invites applications for a tenured or tenure-track faculty position involving both research and teaching. Primary areas of interest include Manufacturing Systems (CIM/FMS), Quality Control, CAD/CAM, Production Systems; background in Engineering Management is desirable. Candidates must have an earned Ph.D. in engineering. Located in southeastern Michigan, O.U. is a state-assisted institution enrolling 12,000 students. The ESE undergraduate programs are ABET accredited; M.S. (in systems engineering, electrical and computer engineering, and engineering management) and Ph.D. programs have about 200 students. The department is funded with grants from government, industry and the State of Michigan. Adjacent to campus is one of the fastest growing technology parks in the U.S. Send current resume, statement concerning

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teaching and research interests, and a list of three references to: Professor Naim A. Kheir, Chair, ESE Department, Oakland University, Rochester, MI 48309-4401. Citizenship and/or immigration status should be stated. Review of applications will begin December 1, 1994. O.U. is an Equal Opportunity and Affirmative Action employer and encourages applications from women and minorities.

Graduate Research Assistantships are available for graduate students pursuing the M.S. or Ph.D. degrees in Electric Power Systems at Clemson University. Funding is available through Clemson University Electric Power Research Associations (CUEPRA), NSF, and research contracts with power companies. Research assistantships consist of a monthly stipend and tuition fee reduction. For United States citizens, Industrial fellowships are also available, on a competitive basis. For further information, contact Dr. Adly A. Girgis, ECE Department, Clemson University, Clemson, SC 29634-0915.

Head, Department of Electrical and Computer Engineering: Clemson University, the land grant university of South Carolina, invites applications and nominations for this position. The College of Engineering is the core of the University and is playing a very important role in the economic development of South Carolina. Both the electrical engineering and computer engineering programs are ABET accredited. The Department offers B.S., M.S., and Ph.D. degrees in each program with approximately 451 undergraduates (not including freshmen), 170 graduate students and 34 full-time faculty positions. Last year, sponsored research exceeded \$2 million. Required qualifications include: (i) earned doctorate and qualification for appointment as full professor, (ii) vision and commitment to planning, (iii) demonstrated administrative and leadership ability and (iv) ability to develop consensus and promote the well being of the department and the college. Send letter of application, names of at least three references and a curriculum vitae or letter of nomination to: Chair ECE Department Head Search Committee, 109 Riggs Hall, Box 340901, Clemson, SC 29634. Review of applicant's file will begin December 1, and will continue until the position is filled. Clemson University is an Equal Opportunity/Affirmative Action Employer. Women and minority candidates are encouraged to apply.

Rice University, Department of Electrical and Computer Engineering, is seeking imaginative and dynamic candidates with an exceptional record of research accomplishments in the area of electronic materials for the Stanley C. Moore Chair in Engineering. The successful candidate is expected to perform an innovative research program in an area of electronic materials and/or devices which transcends traditional boundaries. Of particular interest is research being performed on the nanometer scale, complementing the newly-announced Nanotechnology Initiative at Rice, the Rice Quantum Institute, and the Physical Electronics group of the ECE Department. The candidate must also have a strong commitment to teaching at both the undergraduate and graduate level. Candidates should send a resume, including names of references and a research description, to the Chair, ECE Department, Rice University, Houston, TX 77251-1892. Applications should be received by January 1, 1995. Rice University is committed to attracting qualified persons of diverse backgrounds to its faculty, and is an Equal Opportunity/Affirmative Action Employer.

The Electrical Engineering-Electrophysics Department of the University of Southern California invites applications for tenure-track faculty positions at the assistant professor level in the areas of Circuits and Analog Microelectronics. Candidates must have a Ph.D. and strong interest in teaching, research, and supervising M.S. and Ph.D. candidates. Resume and names of three references should be sent to Prof. H.H. Kuehl, Chair, EE-EP, PHE 604, University of Southern California, Los Angeles, CA 90089-0271.

Dean, Thayer School of Engineering, Dartmouth College: Applicants should have a doctoral degree in engineering or a closely-related field and be eligible for a tenured full professorship in engineering as demonstrated by experience and excellence in teaching and research. Send your nomination, or application with supporting materials, to Professor Bengt Sonnerup, Chair, Thayer School Dean Search Committee, 6004 Parkhurst Hall, Dartmouth College, Hanover, NH 03755-3529 (Inquiries: 603/646-2883; sonnerup@dartmouth.edu). Review process starts in October 1994. Dartmouth College is an Affirmative Action, Equal Opportunity Employer.

The Queen's University of Belfast, Royal Academy of Engineering/Northern Telecom Research Chair of Telecommunications Systems Engineering, School of Electrical Engineering and Computer Science: Applications are invited for a new Research Chair which has been established in the Department of Electrical and Electronic Engineering (rated 5 by the Universities Funding Council). This prestigious position is being funded by Northern Telecom and the Royal Academy of Engineering. The principal aim of the Chair is to establish and lead a research group of international standing in Telecommunications Systems Engineering at Queen's. Major emphasis will be placed on the quality of the research of the applicant; however an interest in the development of research in telecommunication transmission systems would be an advantage, as this is directly relevant to the industrial sponsor, Northern Telecom. Applicants must have a degree or equivalent in electrical/electronic engineering or a related subject, a PhD or equivalent in a relevant field and an international reputation in telecommunications research. A minimum of six years of research experience is essential. Experience of working with, or in, industry is desirable, as the applicant will be expected to collaborate with Northern Telecom and BNR worldwide in this challenging area of research. Enquiries may be directed to Professor F J Smith, Director of the School of Electrical Engineering and Computer Science (telephone (0232) 245133 ext 4072, Fax (0232) 666520). Salary is within the professorial range, with eligibility for USS, and there is an attractive package to assist with relocation and re-settlement expenses. Further particulars are available from the Personnel Officer, The Queen's University of Belfast, BT7 1NN Northern Ireland (telephone (0232) 245133 ext. 3044/3246 or Fax (0232) 324944/310629). Closing date: 14 October 1994. Committed to an Equal Opportunities policy and selection on merit, the University welcomes applications from all sections of the community. Under its affirmative action programme it particularly welcomes applications from women for academic posts. It reserves the right to interview only those applicants who appear, from the information available, to be the most suitable in terms of experience, qualifications and other requirements of the post advertised.

University of Maryland, Department of Electrical Engineering: The University of Maryland at College Park Department of Electrical Engineering expects to have openings for regular faculty positions starting either January or August 1995. Applicants at all ranks will be considered. Candidates for the rank of Assistant Professor should have a high potential for both teaching and research. Candidates for the ranks of Associate and Full Professor should have distinguished records in research and a strong interest in educational programs. Applications, including resume, list of publications, and the names of at least four references should be sent to Dr. Nariman Farvardin, Acting Chair, Department of Electrical Engineering, University of Maryland at College Park, College Park, MD 20742. The University of Maryland is an equal opportunity, affirmative action employer with a strong commitment to the principle of diversity. In that spirit, applications from minority groups and women are especially invited.

Cornell University - Faculty Positions: The Cornell University School of Electrical Engineering has faculty openings at all levels in information technology. We are especially interested in applicants for senior positions and in

applicants interested in the design of digital systems. Candidates should have strong commitments to and outstanding achievements in research and teaching. Applicants' research areas should articulate with the National Information Enterprise, broadly construed to include such disciplines as: cable, fiber and wireless communication and computer networks; processing, compression, recognition, interpretation, security, distribution, retrieval and display of data, speech, image, video and multi-spectral signals; machine vision, machine learning, and architectures for parallel and distributed algorithms; human-machine interfaces with emphasis on handicapped access; broadband switching and high performance computing in support of such applications as interactive TV and HDTV, teleconferencing and telemedicine. Interested persons should submit a letter of application, professional resume, and the names of at least four references to: Director, School of Electrical Engineering, Phillips Hall, Cornell University, Ithaca, NY 14853-5401. Cornell University is an Affirmative Action/Equal Opportunity Employer.

Dean, College of Engineering and Applied Sciences, Arizona State University: Arizona State University invites nominations and applications for the position of Dean of the College of Engineering and Applied Sciences. The University: Arizona State University is a Research I university comprised of 13 colleges. Over 10,000 of its more than 42,000 students pursue graduate studies. ASU is a multi-campus university. The main campus is near the heart of metropolitan Phoenix in the city of Tempe. Phoenix is a cosmopolitan, culturally diverse area of approximately 2 million people, with a very high concentration of high-tech industries. The College: The college has 8 research centers and 9 academic departments in the School of Engineering, the Del E. Webb School of Construction, the School of Technology, and the School of Agribusiness. Enrollment in the college includes 4,200 undergraduate baccalaureate students and 2,100 graduate students with 240 tenured or tenure-track faculty members. The research awards received in 1993-94 totaled approximately \$12.6 million. The College of Engineering and Applied Sciences has been recognized for its innovative Engineering Excellence Program, a three-way partnership between state government, industry, and the university. More than \$175 million has been invested in achieving this goal. In recent years, the college was identified by U.S. News and World Report as one of the top up and coming colleges of engineering in the United States. Duties and Responsibilities: As the chief academic and administrative officer of the college, the dean reports directly to the senior vice president and provost. The dean provides leadership in ensuring academic excellence in all curricula and programs, and support to the faculty for achieving and maintaining quality teaching, research, and service. The dean is responsible for developing strong external support, including support among alumni and industry leaders. Qualifications: Candidates for the position must meet the requirements for appointment at the rank of professor in one of the departments within the college. (The requirements include an earned doctorate degree, a significant record of scholarly and research accomplishments, demonstrated effectiveness in undergraduate and graduate teaching, and evidence of quality service.) Candidates must have appropriate administrative experience through which they have developed strong leadership, communication and interpersonal skills. A successful record of promoting cultural diversity is essential. Nominations and Applications: Applicants must supply a letter of interest, a curriculum vitae, and names, addresses and telephone numbers of only three references. Applications and nominations will be handled confidentially. The search committee will begin to review applications on October 15, 1994. Applications received after that date will be reviewed on a bi-weekly cycle, as necessary, until the position is filled. Preferred starting date is July 1, 1995, but the date is negotiable. Salary is competitive. Send materials to: Dr. Robert E. Barnhill, Chair, College of Engineering Dean Search, Office of the Senior Vice President and Provost, Arizona State University, Box 872803, Tempe, AZ 85287-2803. Arizona State University is an Equal Opportunity, Affirmative Action Employer.

University of Central Florida (UCF), Department of Electrical and Computer Engineering: The Department of Electrical and Computer Engineering, a Ph.D. granting department with 37 faculty, 1,000 undergraduates, 640 graduates, anticipates tenure-track openings at the assistant and associate professor levels. All areas of computer engineering will be considered. Positions are available, starting January and August 1995. Salary and rank are commensurate with qualifications. All applicants must have a Ph.D. in computer engineering or a closely related field at the time of employment and a strong commitment to teaching and research. Applications must be postmarked by November 3, 1994 and must be sent to Dr. W. B. Mikhael, Acting Chair, Electrical and Computer Engineering, University of Central Florida, Orlando, Florida 32816-2450. UCF is an equal opportunity/affirmative action employer. As an agency of the State of Florida, all application materials and selection procedures are available for public review.

Semiconductor Devices and Materials, Electrical Engineering: The Department of Electrical Engineering invites applications for tenure-track faculty in the area of semiconductor devices and materials. Applicants must have a Ph.D. in electrical engineering or a closely related field. We are looking for candidates with interests in electronic and/or optoelectronic devices. Candidates with a strong background in the applications of electromagnetics and quantum principles to these areas are particularly encouraged to apply. We are seeking a highly qualified person who is committed to a career in experimental research and teaching. The Department of Electrical Engineering has modern facilities for device processing and analysis, including Class 10 and Class 1000 clean rooms with a mask aligner for sub-micron device fabrication, an MBE crystal growth system, a 50 GHz network analyzer and wafer prober, and specialized laboratories with instrumentation for the evaluation of microwave and optical devices and materials characterization. Please send a resume, a description of research and teaching interests, and the names and addresses of three references to: Search Committee/DM, Department of Electrical Engineering, University of Delaware, Newark, DE 19716. Review of applications will begin October 15, 1994. Applications will continue to be accepted until the position is filled or until December 1, 1994. The University of Delaware is an Equal Opportunity Employer which encourages applications from Minority Group Members and Women.

Computer Engineering, Electrical Engineering: The Department of Electrical Engineering invites applications for tenure-track faculty in the area of high-performance computer engineering. We seek candidates with a strong interest in the architecture and implementation of advanced computer and computer network systems. Applicants must have a Ph.D. in electrical engineering or a closely related field. The successful applicant would be expected to carry out a vigorous research program in computer engineering and to teach and supervise students at both the undergraduate and graduate levels. The Electrical Engineering Department is well-equipped and maintains a large number of workstations for use in VLSI design, modeling and simulation, signal and image processing, and computer networking research. Excellent computer networking facilities are available, including department Ethernets and a multi-megabits/second campus backbone connected to regional and national backbones. Please send a resume, a description of research and teaching interests, and the names and addresses of three references to: Search Committee/CpE, Department of Electrical Engineering, University of Delaware, Newark, DE 19716. Review of applications will begin October 15, 1994. Applications will continue to be accepted until the position is filled or until December 1, 1994. The University of Delaware is an Equal Opportunity Employer which encourages applications from Minority Group Members and Women.

Director of Marine Science, Environment and Technology: Applications and nominations are invited for the position of Director of the Center of Marine Science, Environment and

Technology at UMass Dartmouth. Candidates must hold an earned doctorate in a marine science or engineering related discipline and meet the standards for a tenure appointment at the full professor level in a science or engineering department. The candidate must also have a record of significant accomplishment in marine science/environment/technology administration and development, and have a strong record in the development and execution of marine-related grant supported research. The Director will be responsible for coordinating present marine activities and providing leadership in the further development of UMass Dartmouth's marine science/technology, environmental and aquaculture programs. These duties will include representing UMass Dartmouth during the final stages of architectural work and construction of its new marine laboratory located on Buzzards Bay in New Bedford. The Director will be responsible for the operation of this laboratory and a planned aquaculture laboratory located on an adjacent site. Responsibilities will include the facilitation and development of linkages and collaborations with key academic/research institutions, government agencies and the private sector. As the laboratories come on line, the Director will be responsible for developing and executing budgets and for developing plans for staffing and support, including the initiation of Sea Grant activities. UMass Dartmouth is one of five campuses in the University of Massachusetts system. Developing new Masters and PhD programs in selected areas of strength and continuing excellence in teaching and research are central to the university's academic mission. In addition, the university is committed to fostering economic development, serving as a catalyst for regional initiatives, providing research and consultation to the local community, and addressing the cultural and educational needs of a diverse population. Located 60 miles south of Boston and 30 miles east of Providence, RI, and 40 miles from Woods Hole, its modern 710 acre suburban campus has a full-time faculty of 330 and a student enrollment of 6000 full- and part-time students. A complete application packet consists of: curriculum vitae, a statement of interest in the position and the names and addresses of four referees. Send materials to Chairperson, Search & Screen Committee, Director of Marine Sciences, c/o Personnel Office, University of Massachusetts, Dartmouth, N. Dartmouth, MA 02747. Screening of applications will begin on October 1, 1994 and continue until the position is filled. The University of Massachusetts Dartmouth is an equal opportunity, affirmative action employer. Women and minorities are especially encouraged to apply.

West Virginia University, Director of Program Development, Science and Engineering: West Virginia University is seeking a dynamic and experienced scientist or engineer to support the University's continuing growth in competitively funded programs of research and scholarship in the physical and biological sciences and in engineering. West Virginia University, the land-grant, doctoral granting research institution in the State of West Virginia has been designated a Research I University by the Carnegie Foundation. The University is committed to fostering basic and applied research and scholarship, providing high quality instructional programs and to supporting public service activities within West Virginia. Nearly 23,000 students are presently enrolled in 175 degree programs. The University is located in Morgantown, a community of approximately 50,000 with ready access to Pittsburgh, PA and Washington, DC. Responsibilities: The Director of Program Development, Science and Engineering, is responsible to the Associate Provost for Research and Economic Development for developing and expanding the University's relationships and contacts with current and potential sponsors of competitively funded research and scholarship in the broadly defined physical and biological sciences and in engineering. Specific activities will include: Building upon extant resources, enhance the dissemination and use of funding opportunities to appropriate faculty. Based on developed opportunities and/or emergent research interests, actively support the development of research teams or groups for intra- or inter-disciplinary activities. Assist with and participate in proposal

development and support negotiations with sponsors in concert with existing staff. Develop and participate in faculty development activities to enhance competitiveness and improve proposal writing skills. Qualifications: Fully qualified candidates are expected to have demonstrated the following capabilities: Proven executive leadership including a commitment to excellence in research and scholarly activities, and a high level of energy and enthusiasm. Demonstrated ability to work with faculty from diverse disciplines, and a variety of professional staff, in developing new thrusts and directions in research. Capable of being an articulate advocate and spokesperson for the University's diverse research and scholarly activities in science and engineering. An earned doctorate and experience in research and research development. Substantial experience with or in funding agencies, with an appropriate science or engineering degree may also be considered. Schedule: To ensure full consideration, send a cover letter, complete resume, and the names and addresses of three references by November 15, 1994 to: Ms. Miriam L. Nitshe, Search Coordinator, Search Committee - Director of Program Development, Science and Engineering, West Virginia University, PO Box 6216, Morgantown, West Virginia 26506-6216. West Virginia University is an Equal Opportunity/Affirmative Action Employer.

The University of Iowa, Department of Electrical and Computer Engineering: Applications are invited for tenure track faculty positions at all ranks. Positions are available starting in the Spring or Fall semester of 1995. Candidates should have interest or research expertise in the disciplines of Electrical and Computer Engineering. Preference will be given to candidates according to the following prioritized list of areas: VLSI (A); Computer Graphics and Visualization or High Speed Networks or Wireless Computing (B); Image Processing or Neural Networks or Signal Processing (C); and Photonics (D). An earned Ph.D. in Electrical and Computer Engineering or an allied field is required. Faculty responsibilities include effective classroom teaching at the undergraduate and graduate levels, developing curricula and laboratories, supervising M.S. and Ph.D. student research, publishing journal articles, and developing and maintaining an externally-funded research program. Interested candidates should submit a letter stating their areas of specialization and a current curriculum vita to: Chair, Faculty Recruiting Committee, Department of Electrical and Computer Engineering, The University of Iowa, Iowa City, Iowa 52242. Applications will be reviewed starting November 15, 1994 and will be accepted until the positions are filled. Women and minorities under-represented in the engineering profession are especially encouraged to apply. The University of Iowa is an Equal Opportunity/Affirmative Action Employer.

Massachusetts Institute of Technology, Faculty Positions: The Department of Electrical Engineering and Computer Science seeks candidates for faculty positions starting in September 1995. We anticipate openings for several junior faculty appointments for individuals who are completing, or who have recently completed, a doctorate. Faculty duties include teaching at both the graduate and undergraduate levels, research, and supervision of theses. We are interested in candidates in most areas of electrical engineering and computer science. All candidates should write to the address below, describing their professional interests and their goals in both teaching and research. Each application should include a curriculum vitae and the names and addresses of three or more references. Additional material, such as papers or technical reports or one letter of reference sent under separate cover, would also be helpful. All candidates should indicate citizenship and, in the case of non-US citizens, describe their visa status. Please respond by February 1, 1995. Send all applications to: Prof. F.C. Hennie, Room 38-435, Massachusetts Institute of Technology, Cambridge, MA 02139. M.I.T. is an equal opportunity/affirmative action employer.

Graduate Fellowships/Research Assistantships in Optics ■ CREOL: The Center for Research and Education in Optics and Lasers (CREOL) at

CLASSIFIED EMPLOYMENT OPPORTUNITIES

the University of Central Florida invites applications from highly qualified students for a number of CREOL Fellowships/Research Assistantships ranging from \$11,000 to \$15,000 per year. Exceptional students will be considered for additional Litton Fellowships of \$4,000. Degrees of M.S. and Ph.D. in Optical Sciences and Engineering, Electrical Engineering, and Optical Physics are offered at UCF. CREOL has 28 faculty devoted to lasers and optical sciences and engineering. The academic program includes specialized courses in electro-optics and lasers, and optical materials as well as fundamental courses in Electrical Engineering, Physics, and Chemistry. Current research areas include laser physics and engineering, such as tunable solid state lasers, free electron lasers and high intensity lasers; studies of nonlinear optical materials and processing of new laser host crystals and optical glasses; thin film optics, diffractive optics, infrared systems, optical design and image analysis, x-ray optics; waveguide optics and devices; and laser applications, including laser materials processing, remote sensing, optical communications, x-ray lithography and microscopy. The application deadline is February 15, 1995. Applications from women, minorities, and handicapped persons are particularly encouraged. To receive an application package, write to: CREOL/University of Central Florida, Graduate Affairs Committee, 12424 Research Parkway, Suite 400, Orlando, FL 32826.

Stanford University: The Operations, Information and Technology (OIT) area at the Graduate School of Business, Stanford University, is seeking qualified applicants for two tenure-track faculty positions starting in the 1995/6 academic year. Applications are sought at the entry level, Assistant Professor and untenured Associate Professor levels. Stanford's OIT faculty seek to integrate, extend and apply various methods and paradigms from the sometimes separate areas of Operations, Information Systems, Management Science and others (such as Engineering and Economics). OIT research involves analytical and empirical study of technological systems, in which technology, people and markets interact. Applicants are expected to have rigorous training in mathematical and/or statistical methodologies. The individuals appointed to these positions will be expected to do innovative research in the OIT field, to participate in the school's Ph.D. program and to teach both required and elective courses in the MBA program. One of the positions is restricted to candidates with primary interests in information systems/technology. Stanford University is an equal opportunity employer and is particularly seeking applications from women and ethnic minorities. Applicants should send ■ resume, names and addresses of three references, examples of recent written work and evidence of teaching performance (if available) to: Academic Affairs Coordinator, Box 0, Graduate School of Business, Stanford University, Stanford, CA 94305-5015. Deadline for receipt of completed applications is December 15, 1994.

Government/Industry Positions Open

Manufacturing Engineer: A challenging and rewarding position is open for ■ highly motivated individual with exceptional manufacturing abilities and excellent academic credentials in basic physics and mechanical engineering. Minimum requirements include a masters degree in engineering or science and two years of diverse manufacturing experiences including precision tooling and complex product design. Electronics and automotive repair experience also desirable. Doty Scientific is an attractive high-tech manufacturing and R&D company with an excellent twelve-year growth record now entering a rapid growth phase. Competitive salary and benefits commensurate with abilities and experience. Send resume, including copy of transcripts, GRE or SAT scores, and list of patents and publications to: Judy Doty, Doty Scientific, Inc., 700 Clemson Rd., Columbia, SC 29223.

Marketing/Account Manager to provide advice to customers on various automated welding applications and on equipment usage; provide advice to engineering staff on the development of control algorithms to be integrated in welding control systems; development of marketing materials to be presented to target industries; and provide technical advice to research engineers involved in the development of new automated welding equipment and related tooling. Responsible for major automaker's accounts and marketing of resistance weld controls. Requires an Associates Degree in Electronics Engineering Technology and six years experience in the job offered or six years experience as a Sales and Applications Manager; this experience must be in resistance welding controls; 40 hours per week; 8:00 a.m. to 5:00 p.m.; \$45,900.00 per year. Send resumes to 7310 Woodward Avenue, Room 415, Detroit, Michigan 48202. Reference No. 71194. "Employer Paid Ad."

Service Engineering Manager to provide advice to customers on selection of resistance welding controls to fit engineering specifications and requirements using engineering background; provide advice to customers on writing, testing, trouble-shooting and other technical information; and serve as a liaison between sales, engineering and the service department, and between foreign and U.S. subsidiaries, including: recruitment, training and development of customer service employees (in house and field). Requires an Associates Degree in Electronics Technology and two years experience in the job offered or two years experience as a Plant Manager; this experience must include production of resistance weld controls; 40 hours per week; 8:00 a.m. to 5:00 p.m.; \$42,180.00 per year. Send resumes to 7310 Woodward Avenue, Room 415, Detroit, Michigan 48202. Reference No. 71094. "Employer Paid Ad."

Sales Project Engineer for machine tool manufacturer in Southwest Ohio. Prepare computer integrated flexible manufacturing system (FMS) proposals, using technical and engineering information, which are customer responsive, timely and competitive. Interpret and evaluate customers' needs and requests and recommend direction for attainment of this solution and development of appropriate marketing strategy. Communicate customer information to appropriate internal company groups, schedule activities, contribute to proposed solution, gather, organize and negotiate cost inputs, and compose and assemble proposal text. Will work primarily with customers in the Far East (China, Taiwan, Hong Kong and Singapore). Job requires Bachelors Degree in Control Engineering or Electrical Engineering with specialization in Control Engineering and four years sales engineering or project management experience. The four years experience must be in formulation of proposals, selection of proper machinery, pricing, and working with vendors for Flexible Manufacturing Systems (FMS). Experience must also be in application engineering with FMS, Computer Numerical Control (CNC) machining centers and manufacturing cells. One year of this experience must be with automated production system (CIM). Must be fluent (speaking, reading and writing) in Mandarin Chinese. Must be willing to travel to Far East approx. 20-30% of the time. 42.5 hrs/wk; 8:00 a.m. - 5:00 pm. Salary: \$46,345/yr. Must have proof of legal authority to work indefinitely in the U.S. Send resume in duplicate (No Calls) to K. Shockey, Job #00470, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, Ohio 43216.

Principal Engineer: Research, develop, design and test electronic component products and systems; emphasis in photoelectric sensors for industrial controls mkt; supervise other engineers; oversee major new product design and redesigns; develop and deploy corporate ISO-9000 cert. process; assist design engineering mgr. in implementation of new tooling, test and measurement equip., custom integrated circuits and other new technology; recommend and

evaluate new capital equip. and software; consult with major customers and potential customers; provide technical expertise for new product opportunities. Requires ■ B.S. in Electrical Engineering and 8 yrs exp. Related occupation exp. must include photoelectric sensor design in business setting, supervision of other engineers, and in-depth customer interaction. This is a full-time position at our Everett, WA facility. \$5906.00/mo. OT as needed. Must have proof of legal authority to work permanently in the USA. By Oct. 31, send resume to: Employment Security Department, E&T Division, Job #429907, P.O. Box 9046, Olympia, WA 98507-9046. An employer Paid Ad. No calls.

Research and Development Engineer: Major corporation involved in the manufacture and sale of ophthalmic lenses seeks to employ a Research and Development Engineer for its office in Brooklyn Center, Minnesota. The Research and Development Engineer will be required to (i) engineer all aspects of research and development projects required to bring new ophthalmic lens products from concept to manufacturing to the marketplace, (ii) utilize multiple project management skills in order to effectively plan and design projects, recommend and justify capital investment, coordinate and engineer research and development studies and make smooth transitions from prototype to manufacturing with budgeted resources and time, (iii) research and develop new thermoplastic materials for molding operation, (iv) develop projects for hardcoating of lenses for cost reduction and improved product performance, (v) provide engineering details on processing effects on final lens configuration and (vi) evaluate and recommend the purchase of new equipment for current and future manufacturing processes. Candidates must (i) hold at least a Master of Science in Plastics Engineering, and (ii) have at least two (2) concurrent years of experience with: (a) plastics processing, product design and Computer Aided Engineering, (b) making precision ophthalmic products, (c) injection molding process and equipment, (d) post-molding coating operations and ASTM testing procedures, (e) project management with multiple engineering projects from concept to finish, and (f) dealing with primary ophthalmic lens vendors and suppliers. Salary: \$43,900 per year. Job Site: Brooklyn Center, Minnesota. Hours: 40 hours per week, 8:00 a.m. to 5:00 p.m. Applicants meeting all of the above requirements may submit ■ cover letter and a copy of their resume to: B. Abraham, #4-055, MDES, 390 North Robert Street, Third Floor, St. Paul, Minnesota 55101.

Engineer, Solid State Device: Brewer Science, Inc. is seeking an individual to facilitate the development and commercialization of micro-machined devices based on a new conducting polymer technology. Requirements include ■ strong background in physics, solid state device engineering, or a related discipline, as well as experience in marketing new technologies. A Ph.D. degree or commensurate experience is preferred. Please send your resume to Brewer Science, Inc., Attn: MM, P.O. Box GG, Rolla, MO 65401. EOE

Product Engineer to design, develop & release Electronic Control Modules & components for Supplemental Restrain Systems, Automotive Controls, Information & Convenience for light duty truck & truck components; coordinate design verification & Product validation testing with suppliers; develop & coordinate design, process & system FMEA; coordinate diagnostic & service procedures development; work with suppliers to reduce system cost & improve reliability on all components; coordinate with project management, suppliers, quality assurance, reliability, vehicle development, assembly plants & wiring groups; Reqs: Bach. in Electrical or Electronic Engg., 2 yrs. exp. in job offered or 2 yrs. related exp. as Product Designer. Related exp. must include computer-aided design of light duty trucks & truck components; \$23.50/hr, 40 hrs/wk, 8a-5p. Send resume to 7310 Woodward Ave., Room 415, Detroit, MI 48202. Ref. #83494. "Employer Paid Ad"

Neurocontrol Engineer: Develop neural, intelligent and learning control theory systems for

1 PRODUCT AND ADVERTISING INFORMATION

1	17	25	33	41	49	57	65	73	81	89	97	105	113	121	129	137	145	153	161	169	177	185	
2	10	18	26	34	42	50	58	66	74	82	90	98	106	114	122	130	138	146	154	162	170	178	186
3	11	19	27	35	43	51	59	67	75	83	91	99	107	115	123	131	139	147	155	163	171	179	187
4	12	20	28	36	44	52	60	68	76	84	92	100	108	116	124	132	140	148	156	164	172	180	188
5	13	21	29	37	45	53	61	69	77	85	93	101	109	117	125	133	141	149	157	165	173	181	189
6	14	22	30	38	46	54	62	70	78	86	94	102	110	118	126	134	142	150	158	166	174	182	190
7	15	23	31	39	47	55	63	71	79	87	95	103	111	119	127	135	143	151	159	167	175	183	191
8	16	24	32	40	48	56	64	72	80	88	96	104	112	120	128	136	144	152	160	168	176	184	192

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2 ADDITIONAL COMMENTS

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 Void after January 1, 1995 Void overseas after January 1, 1995 10/94

troubleshoot & repair existing process equipment controls; Reqs: Bach. in Electrical Engg. or Electrical Engg. Tech., 2 yrs. exp. in job offered or 2 yrs. related exp. as an Electrical Engineer. 2 yrs. related exp. must include PLC programming, control circuit design & control circuit troubleshooting; \$39,805/yr. 40 hrs/wk. 6:30a-3:30p. Send resume to 7310 Woodward Ave., Room 415, Detroit, MI 48202. Ref. #84894 "Employer Paid Ad"

Fiber Optic Design Engineer needed to research, design, and develop specialized fiber optic cables for communication networks consisting of passive components, such as connectors and splices, and active components, such as lasers and laser diodes. Optimize cable designs to meet specifications for optical performance in various operating conditions. Utilize computer skills to allow programming and mathematical modeling of cable performance over a wide range of temperatures and loading conditions. Determine specifications for installation and operation of fiber optic cables in order to maintain high levels of optical performance over the cable lifetime. Design inspection instruments to test optical fibers, fiber optic cables or their parts for defects, such as excessive attenuation of transmitted optical power. Requirements are M.S. degree in Optics and Optoelectronics and computer fluency in Fortran, Basic, and Lotus 1-2-3 programs. Forty (40) hours/week - 9:00 a.m. - 5:00 p.m. Salary of \$36,792 annually. Must have proof of legal authority to work permanently in the United States. All responses must include Social Security Number. Send two copies of resume (no calls) to Job Service, Route 3, Box 153, Newton, North Carolina 28658, J.O. # NC4440238, DOT # 003.061-034.

Senior Systems Analyst: International graphics equipment and supplies company seeking Senior Systems Analyst in Washington facility. Candidate will be responsible for analyzing, developing, and modifying complex software systems; designing, coding, testing and debugging programs. Must possess a bachelors degree in computer science or mathematics; a minimum of 2 years experience as a Senior Systems Analyst or Systems Programmer in the printing or publishing industry; and one year experience with OS/2-1.3,2-1.2 Presentation Manager and Raina Data Server or Raina Data Manager. Must be prepared to travel and work "on-site" for extensive periods of time. Minimum 40 hours per week at \$54,000.00 per year. By October 30, 1994, send resume to:

Senior Engineers/Specialists-Saudi Arabia: Specialists in Packet Switching including: Network planning, Customer Service, Training, Marketing, Transmission, Switching, Signaling and Power systems. B.S. Telecom, Bus. or E.E. Degree only - minimum 8 years experience. U.S.A., Canadian, Australian citizenship only. Positions require independent technical skills and ability to liaison with Saudi Government. Housing, transportation, etc. provided. 3 yr. contract. Single status. Salary range \$40k to \$60K U.S. ECSE, Telecom Consultants, Attn: M. Glenn, 1857 Colorado Ave., Boise, Idaho 83706. Tel. (208) 383-9090 or Fax 331-3007.

Optical engineer with excimer laser experience to develop an eye surgical device for human use. Call Dr. Epstein at 1-815-363-2020.

Engineer, Software Development: Dev. & design VLSI CAD tools for IC place & route apps. PhD in EE, Comp. Eng. or Comp. Sci. reqd. \$5666.66/mo. 40 hr/wk. Knlg. of VLSI sys. automation design methodology, stochastic search algorithm research (simul. evolution, & simul. annealing), CMOS module generator dev. for random logic synth., place & route technlg. (timing-driven placement, global route), VLSI sys. & logic design, & C reqd. Job site/interv.: San Jose, CA. Send ad & resume to: IEEE Spectrum, Box 10-1, 345 East 47th Street, New York, NY 10017.

Electrical Engineer: 40 hrs./wk.; 9 am to 5 pm; \$36,200 per year. Use programmable logic controllers to design and develop high level electrical systems for screen printing machines for use by printing companies. Must have 2 yrs. experience in job offered or as a Senior Engineer. Experience in job offered or as Senior Engineer must include 2 years using Programmable Logic Controllers and doing technical drawings on a computer. Must have taken academic or non-academic course in Programmable Logic Controllers. Must have proof of legal authority to work permanently in the U.S. Send resumes to: Illinois Department of Employment Security, 401 S. State Street - 3 South, Chicago, Illinois 60605, Attention: James Gregory. Reference # V-IL 11937-Z. No Calls. An Employer Paid Ad - Send 2 copies of resume.

Engineer, Software III, Chip Architecture: Responsible for developing, coding and debugging software for complex algorithms for a developer of integrated circuit products, in all the following areas: Synthesis, place, and route, timing optimization, and partitioning. Requires a M.S. degree in E.E. or C.S. & two years of ex-

perience in chip architecture development or or C.S. & adv. know. of chip architecture. Also requires knowledge of design cycle for programmable gate arrays; tools used in chip design, such as:ilog, Berkeley MIS; of research & development algorithms; of probability & stochastic simulation; of dev. of custom integrated in electronic circuit design; of dev. & programming in C & UNIX; sign & dev.; of VLSI circuit design of computer design internals. hrs./wk. Job/interv. site: San Jose, v/resume to Job # JB50012, P.O. Sacramento, CA 95826-9065.

object engineer for industrial automation systems company in NE area: design, implement & test automation systems for steel rolling & process user automation needs; studies on customer's existing electrical schematics; develop programs, layout drawings & system electrical, electronic & software user equipment with monitoring system Distributed Control System software, simulation & process optimization tools used: Allen-Bradley Programmable Logic Controllers, Intel Multibus Reliance Programmable Logic Must have M.S. in Electrical or Systems Engineering or Engineering and 2 yrs exp in job development with writing software for systems for steel rolling using at least 3 controllers: Intel Multibus Reliance Programmable Logic Controllers or Allen-Bradley Programmable Logic Controllers and one year work or graduate research in A/D conversion, real time data acquisition, process control design. 40 hrs/wk, 8am-5pm, Mon-Fri, \$43,160 per yr. Must have proof of legal authority to work indefinitely in U.S. Send resume in duplicate (no calls) to R. Lechler, Job #00229, Ohio Bureau of Employment Services, PO Box 1618, Columbus, OH 43216.

Object-Oriented Technologist: The ideal candidate will meet or exceed the following requirements: Masters degree in software engineering or equivalent, Ph.D. desirable; three years OO experience; demonstrated excellence in teaching/consulting/programming; knowledge in and of the following specialized areas: C++, Smalltalk, systems design, database design. Duties include training and consulting. Customer sites vary geographically; most positions require travel. Relocation to corporate headquarters not required. Top salary for top people. Contact: Madeleine Moore, Secretary at Paradigm Shift, Inc., P.O. Box 5108, Potsdam, NY 13676, Fax 315-353-6110, moore@parashift.com.

In Seattle, WA; software engineer, export for US-made software and related hardware. Write software in various languages, including C, custom tailor program to customer needs. 3 years experience in Russian computer distribution channels. Travel regularly to Russia. B.S. in computer science or related science. Fluency in Russian and English. 40 hpw, 9:00am - 5:30pm, \$45,000 yr. By November 1, 1994, send resume to: Employment Security Department; E&T Division, Job # 431261; Post Office Box 9046; Olympia, WA 98507-9046.

Electrical Engineer: Design, development & testing of electromechanical & electrical switches & sensors for automotive applications. Responsibilities include writing component technical specifications & test procedures; bench marking competitive products, durability testing, reliability & failure analysis using design of experiment techniques & cost quality analysis. Salary, \$18.87 per hour, 40 hour week (8:00 - 5:00) overtime at a rate of \$28.31 per hour. Requirements, Masters degree in Electrical Engineering; 1 college level course in Transducers & Measurement; Electronic System Design; must have completed 1 graduate level course in each of the following - Electronic Control Systems; Direct Digital Control; Design of Experiments & Computer Applications in Engineering. Send resume to: MESCO, 7310 Woodward Ave., Rm. 415 (Ref. #91394) Detroit, MI 48202. Employer paid ad.

the University of Central Florida offers positions from highly qualified individuals. A number of CREOL Fellowships Assistantships ranging from \$11,000 per year. Exceptional students considered for additional funding \$4,000. Degrees of M.S. and Ph.D. in Sciences and Engineering, Electrical and Optical Physics are offered. There are 28 faculty devoted to laser sciences and engineering. The program includes specialized courses in optics and lasers, and optical materials as fundamental courses in Engineering, Physics, and Chemistry. Research areas include laser processing, such as tunable solid state electron lasers and high intensity of nonlinear optical materials and new laser host crystals and optical film optics, diffractive optics, in optical design and image analysis waveguide optics and devices; applications, including laser materials remote sensing, optical communication lithography and microscopy. The deadline is February 15, 1995 from women, minorities, and persons are particularly encouraged. An application package CREOL/University of Central Florida Affairs Committee, 12424 Res Suite 400, Orlando, FL 32826.

Stanford University: The Operations, Information and Technology (OIT) area at the Graduate School of Business, Stanford University, is seeking qualified applicants for two tenure-track faculty positions starting in the 1995/6 academic year. Applications are sought at the entry level, Assistant Professor and untenured Associate Professor levels. Stanford's OIT faculty seek to integrate, extend and apply various methods and paradigms from the sometimes separate areas of Operations, Information Systems, Management Science and others (such as Engineering and Economics). OIT research involves analytical and empirical study of technological systems, in which technology, people and markets interact. Applicants are expected to have rigorous training in mathematical and/or statistical methodologies. The individuals appointed to these positions will be expected to do innovative research in the OIT field, to participate in the school's Ph.D. program and to teach both required and elective courses in the MBA program. One of the positions is restricted to candidates with primary interests in information systems/technology. Stanford University is an equal opportunity employer and is particularly seeking applications from women and ethnic minorities. Applicants should send a resume, names and addresses of three references, examples of recent written work and evidence of teaching performance (if available) to: Academic Affairs Coordinator, Box 0, Graduate School of Business, Stanford University, Stanford, CA 94305-5015. Deadline for receipt of completed applications is December 15, 1994.

Government/Industry Positions Open

Manufacturing Engineer: A challenging and rewarding position is open for a highly motivated individual with exceptional manufacturing abilities and excellent academic credentials in basic physics and mechanical engineering. Minimum requirements include a masters degree in engineering or science and two years of diverse manufacturing experiences including precision tooling and complex product design. Electronics and automotive repair experience also desirable. Doty Scientific is an attractive high-tech manufacturing and R&D company with an excellent twelve-year growth record now entering a rapid growth phase. Competitive salary and benefits commensurate with abilities and experience. Send resume, including copy of transcripts, GRE or SAT scores, and list of patents and publications to: Judy Doty, Doty Scientific, Inc., 700 Clemson Rd., Columbia, SC 29223.

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field). Requires an Associates Degree in Electronics Technology and two years experience in the job offered or two years experience as a Plant Manager; this experience must include production of resistance weld controls; 40 hours per week; 8:00 a.m. to 5:00 p.m.; \$42,180.00 per year. Send resumes to 7310 Woodward Avenue, Room 415, Detroit, Michigan 48202. Reference No. 71094. "Employer Paid Ad".

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Principal Engineer: Research, develop, design and test electronic component products and systems; emphasis in photoelectric sensors for industrial controls mkt; supervise other engineers; oversee major new product design and redesigns; develop and deploy corporate ISO-9000 cert. process; assist design engineering mgr. in implementation of new tooling, test and measurement equip., custom integrated circuits and other new technology; recommend and

effects on materials configuration and (vi) evaluate and recommend the purchase of new equipment for current and future manufacturing processes. Candidates must (i) hold at least a Master of Science in Plastics Engineering, and (ii) have at least two (2) concurrent years of experience with: (a) plastics processing, product design and Computer Aided Engineering, (b) making precision ophthalmic products, (c) injection molding process and equipment, (d) post-molding coating operations and ASTM testing procedures, (e) project management with multiple engineering projects from concept to finish, and (f) dealing with primary ophthalmic lens vendors and suppliers. Salary: \$43,900 per year. Job Site: Brooklyn Center, Minnesota. Hours: 40 hours per week, 8:00 a.m. to 5:00 p.m. Applicants meeting all of the above requirements may submit a cover letter and a copy of their resume to: B. Abraham, #4-055, MDES, 390 North Robert Street, Third Floor, St. Paul, Minnesota 55101.

Engineer, Solid State Device: Brewer Science, Inc. is seeking an individual to facilitate the development and commercialization of micro-machined devices based on a new conducting polymer technology. Requirements include a strong background in physics, solid state device engineering, or a related discipline, as well as experience in marketing new technologies. A Ph.D. degree or commensurate experience is preferred. Please send your resume to Brewer Science, Inc., Attn: MM, P.O. Box GG, Rolla, MO 65401. EOE

Product Engineer to design, develop & release Electronic Control Modules & components for Supplemental Restrain Systems, Automotive Controls, Information & Convenience for light duty truck & truck components; coordinate design verification & Product validation testing with suppliers; develop & coordinate design, process & system FMEA; coordinate diagnostic & service procedures development; work with suppliers to reduce system cost & improve reliability on all components; coordinate with project management, suppliers, quality assurance, reliability, vehicle development, assembly plants & wiring groups; Reqs: Bach. in Electrical or Electronic Engg., 2 yrs. exp. in job offered or 2 yrs. related exp. as Product Designer. Related exp. must include computer-aided design of light duty trucks & truck components; \$23.50/hr, 40 hrs/wk, 8a-5p. Send resume to 7310 Woodward Ave., Room 415, Detroit, MI 48202. Ref. #83494. "Employer Paid Ad"

Neurocontrol Engineer: Develop neural, intelligent and learning control theory systems for

flight control; implement motor control and inverse kinematics control system; design new neural network paradigms; work with SG Computers and FAME testbed. Req. incl. 8 yrs of college incl. M.S. in EE and at least 25 semester hrs of eng. credit in neural networks, incl. neurocontrol, beyond a M.S. Exp req incl 2 yrs exp in the job offered or 2 yrs of related exp in the field of electrical engineering which incl exp with neural networks for flight control systems; exp with on-line system, work with eng software packages and exp with intelligent and learning control theory. Salary \$45K/yr. Location: Chattanooga, TN. Send resume to Charles Turner, TN Dept of Empl Sec, P.O. Box 11088, Chattanooga, TN 37401. Ref Job Order TN1489573.

Systems Engineer to design, evaluate & analyze system hardware & software on existing test systems, & develop new test systems for domestic & international markets. Requires: M.S. in Electrical Engineering & 5 yrs. exp. in job offered or 1 year in research & development position & knowledge in: R & D methods; PCB production methods; assembly language; automatic firing control systems; technical writing; & digital & analog automatic control testing. Job Site: Carson City, NV. 40 hr. work week. Salary: \$39,582/yr. Proof of authorization to accept permanent, full-time employment in U.S. required if hired. Please submit resume and a copy of this ad to: # 9425742, Nevada Employment Security Div., 70 W. Taylor St., Reno, NV 89509-1700.

Controls Engineer to design, develop & document control circuits & equipment specifications for new & existing machines & troubleshoot & repair existing process equipment controls; Reqs: Bach. in Electrical Engg. or Electrical Engg. Tech., 2 yrs. exp. in job offered or 2 yrs. related exp. as an Electrical Engineer. 2 yrs. related exp. must include PLC programming, control circuit design & control circuit troubleshooting; \$39,805/yr, 40 hrs/wk, 6:30a-3:30p. Send resume to 7310 Woodward Ave., Room 415, Detroit, MI 48202. Ref. #84894 "Employer Paid Ad"

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Senior Systems Analyst: International graphics equipment and supplies company seeking Senior Systems Analyst in Washington facility. Candidate will be responsible for analyzing, developing, and modifying complex software systems; designing, coding, testing and debugging programs. Must possess a bachelors degree in computer science or mathematics; a minimum of 2 years experience as a Senior Systems Analyst or Systems Programmer in the printing or publishing industry; and one year experience with OS/2-1.3.2-1.2 Presentation Manager and Raina Data Server or Raina Data Manager. Must be prepared to travel and work "on-site" for extensive periods of time. Minimum 40 hours per week at \$54,000.00 per year. By October 30, 1994, send resume to:

Employment Security Department, E&T Division, JOB #440419, P.O. Box 9046, Olympia, WA 98507-9046.

Program Manager: By November 1, 1994, please send resume to: Employment Security Department, E&T Division, Job # 450230-P, P.O. Box 9046, Olympia, WA 98507-9046. Job Order Number must be indicated on your response. Job Description: Designs complex software for micro computer software under limited supervision. Coordinates program development, writes functional specifications and standards, and performs functional verification of security and replication components of multiuser relational database software product for international markets. Works with documentation team to ensure accuracy and clarity of documentation and with marketing team to determine technical vision of product. Requirements: Master's degree in Computer Science; 20 course hours in database theory, computer networks, and computer security. Two years work experience in the job offered or as program manager for the development of personal computer database management system software for international markets, to include six months work experience in programming, or providing training or technical support regarding replicated database applications and using advanced feature of Lotus Notes. Experience may be gained concurrently. Must have legal authority to work in the United States. Job Location: Seattle Area Employer. Salary: \$49,500 - \$52,500 per annum, depending on experience. Compensation package includes bonuses and stock options. 40 hours per week, flex time. EOE

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Electrical Engineer: 40 hrs./wk.; 9 am to 5 pm; \$36,200 per year. Use programmable logic controllers to design and develop high level electrical systems for screen printing machines for use by printing companies. Must have 2 yrs. experience in job offered or as a Senior Engineer. Experience in job offered or as Senior Engineer must include 2 years using Programmable Logic Controllers and doing technical drawings on a computer. Must have taken academic or non-academic course in Programmable Logic Controllers. Must have proof of legal authority to work permanently in the U.S. Send resumes to: Illinois Department of Employment Security, 401 S. State Street - 3 South, Chicago, Illinois 60605, Attention: James Gregory. Reference # V-IL 11937-Z. No Calls. An Employer Paid Ad - Send 2 copies of resume.

Engineer, Software III, Chip Architecture: Responsible for developing, coding and debugging software for complex algorithms for a developer of integrated circuit products, in all the following areas: Synthesis, place, and route, timing optimization, and partitioning. Requires a M.S. degree in E.E. or C.S. & two years of ex-

perience in chip architecture development or Ph.D. in E.E. or C.S. & adv. know. of chip architecture development. Also requires knowledge of complete design cycle for programmable gate array; of CAD tools used in chip design, such as Viewlogic, Verilog, Berkeley MIS; of research & dev. of complex algorithms; of probability & stochastic modeling & simulation; of dev. of custom CAD tools used in electronic circuit design; of programming dev. programming in C & UNIX; of compiler design & dev.; of VLSI circuit design & fabrication; of computer design internals. \$63,000/yr. 40 hrs./wk. Job/interv. site: San Jose, CA. Send ad w/resume to Job # JB50012, P.O. Box 269065, Sacramento, CA 95826-9065.

Controls project engineer for industrial controls & automation systems company in NE Ohio. Duties are: design, implement & test automated control systems for steel rolling & processing; analyze user automation needs; conduct field studies on customer's existing equipment & electrical schematics; develop electrical diagrams, layout drawings & system specs; design electrical, electronic & software linkage for user equipment with monitoring devices; design Distributed Control System hardware, software, simulation & process optimizations. Tools used: Allen-Bradley Programmable Logic Controllers, Intel Multibus Controllers & Reliance Programmable Logic Controllers. Must have M.S. in Electrical Engineering or Systems Engineering or Computer Engineering and 2 yrs exp in job described or 1 yr exp with writing software for control systems for steel rolling using at least 2 of the following 3 controllers: Intel Multibus Controllers, Reliance Programmable Logic Controllers or Allen-Bradley Programmable Logic Controllers and one year work or graduate research in A/D conversion, real time data acquisition, process control design. 40 hrs/wk, 8am-5pm, Mon-Fri, \$43,160 per yr. Must have proof of legal authority to work indefinitely in U.S. Send resume in duplicate (no calls) to R. Lechler, Job #00229, Ohio Bureau of Employment Services, PO Box 1618, Columbus, OH 43216.

Object-Oriented Technologist: The ideal candidate will meet or exceed the following requirements: Masters degree in software engineering or equivalent, Ph.D. desirable; three years OO experience; demonstrated excellence in teaching/consulting/programming; knowledge in and of the following specialized areas: C++, Smalltalk, systems design, database design. Duties include training and consulting. Customer sites vary geographically; most positions require travel. Relocation to corporate headquarters not required. Top salary for top people. Contact: Madeleine Moore, Secretary at Paradigm Shift, Inc., P.O. Box 5108, Potsdam, NY 13676, Fax 315-353-6110, moore@parashift.com.

In Seattle, WA; software engineer, export for US-made software and related hardware. Write software in various languages, including C, custom tailor program to customer needs. 3 years experience in Russian computer distribution channels. Travel regularly to Russia. B.S. in computer science or related science. Fluency in Russian and English. 40 hpw, 9:00am - 5:30pm, \$45,000 yr. By November 1, 1994, send resume to: Employment Security Department; E&T Division, Job # 431261; Post Office Box 9046; Olympia, WA 98507-9046.

Electrical Engineer: Design, development & testing of electromechanical & electrical switches & sensors for automotive applications. Responsibilities include writing component technical specifications & test procedures; bench marking competitive products, durability testing, reliability & failure analysis using design of experiment techniques & cost quality analysis. Salary, \$18.87 per hour, 40 hour week (8:00 - 5:00) overtime at a rate of \$28.31 per hour. Requirements, Masters degree in Electrical Engineering; 1 college level course in Transducers & Measurement; Electronic System Design; must have completed 1 graduate level course in each of the following - Electronic Control Systems; Direct Digital Control; Design of Experiments & Computer Applications in Engineering. Send resume to: MESC, 7310 Woodward Ave., Rm. 415 (Ref. #91394) Detroit, MI 48202. Employer paid ad.

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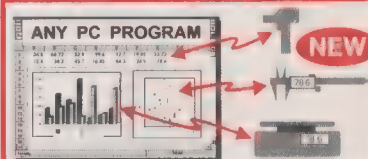
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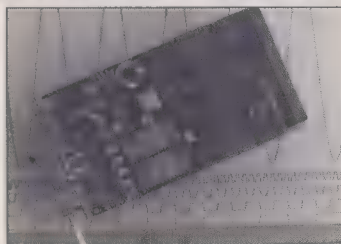
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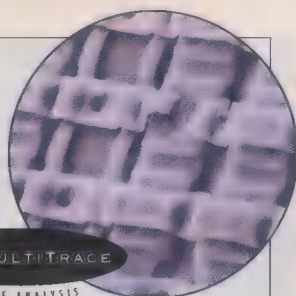
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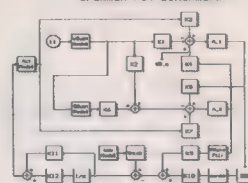
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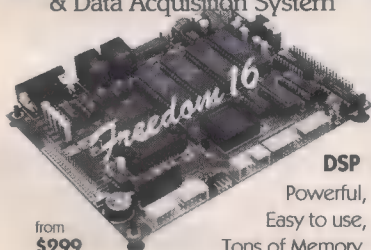
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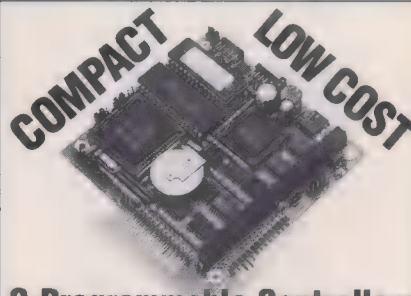


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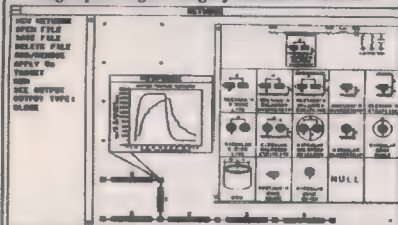
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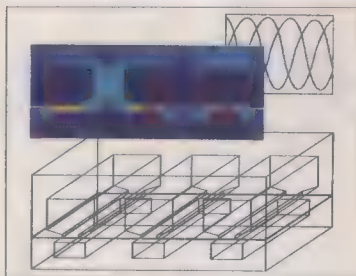
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UNEMPLOYMENT FRONT. A number of the engineers who fell prey to the cutbacks in the defense and aerospace industries tell Senior Editor Trudy Bell about their experiences. Despite the statistics indicating some improvement in other parts of the economy, the job outlook in these areas is not rosy.

GOOD THINGS IN NEW PACKAGES. This fall's software report has two focuses. The first is newly available packages for mathematical manipulation (subdivided into symbolic and numerical calculations), and the second is design automation (also subdivided into software for data analysis and visualization).

Two additional articles tackle other design software. One discusses tools for designing integrated circuits with channel lengths of one-half micrometer or less. The other deals with new approaches to the design of field-programmable gate arrays.

SWORDS = PLOWSHARES. With the decline in defense spending, companies with a military or aerospace orientation are wondering how best to deploy their idle manufacturing capacity and remaining personnel. One road out of their predicament is to develop systems having both military and commercial applications. And there is a methodology for doing just that.

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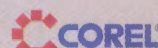
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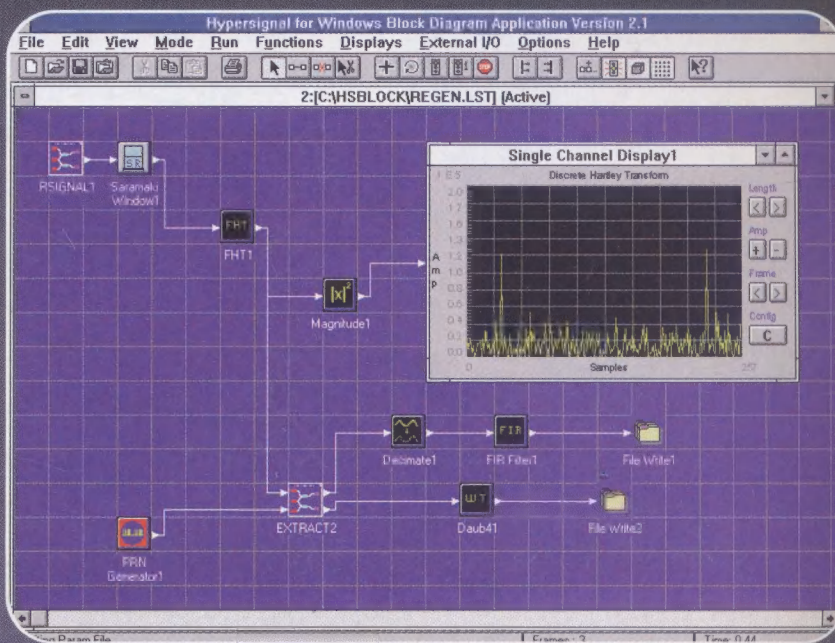
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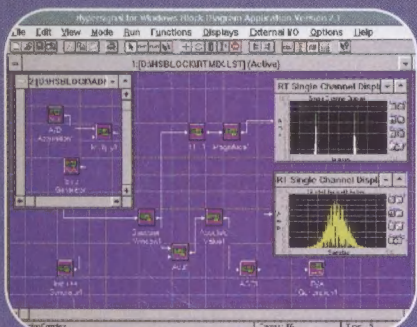


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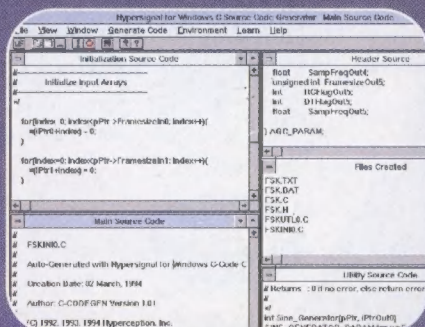
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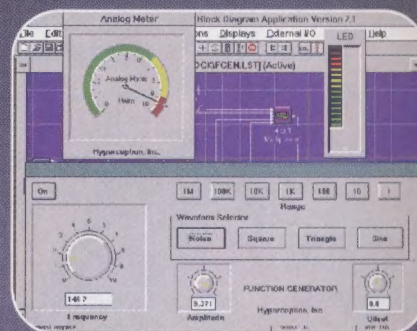
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